ICOS SCIENCE CONFERENCE 2024

Integrated Carbon Observation System

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Book of Abstracts

10

Atmospheric GHG Monitoring Network of the metropolitan area of Barcelona.

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

The ICOS Cities Horizon 2020 project makes observations on Greenhouse Gases (GHG) emissions in densely populated urban areas, with the objective of developing useful tools and services to support the local climate action plans of cities. This project has expanded to 12 European cities, including Barcelona.The Barcelona conurbation area extents up to 4200 km^2 and has a total population over 5 million habitants. It includes green areas, industrial zones and agricultural soils but also some areas with the highest density population in Europe. Four continuous atmospheric measurement stations of GHG have been implemented with Picarro gas analyzers of CO_2 ,CH_4 and water vapor, strategically placed in different characteristic areas of the urban conurbation: the ICM stations is located at the Barcelona seafront, IDAEA station in a university campus near a high traffic route inside Barcelona city, Observatori Fabra in a meteorological observatory in the middle of a mountain range 300m above Barcelona skyline (at 410 meters above sea level), and ICTA in a university building rooftop in the second metropolitan ring.

Here we present the results of the first two years of atmospheric monitoring data for these stations. The CO_2 and CH_4measurements are complemented with meteorological measurements to know the precedence of the air masses. The data obtained is used study the meteorological influence on concentrations and estimate the city's budget emissions with the help of models, in the frame of the URBAG project.

11

Carbon Dew Community of Practice: Anchoring Fair and Equitable Climate Solutions in Direct Atmospheric Flux Measurement

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Theme

15. Science communication and outreach to increase the impact of climate research

Abstract Text

The Carbon Dew Community of Practice is an international non-profit representing carbon and climate experts from over 180 organizations. Our vision is to anchor fair and equitable climate solutions in direct atmospheric measurements, and our mission is to facilitate technology transfer by providing a medium for public and private entities to work together towards common goals. We strive to translate surface-atmosphere science into real-world impacts and innovate industry practices with the best available science. To achieve this, we support the integration and coordination of existing capabilities and resources for enhancing the measurement and quantification of GHG emissions and removals.

Initial Endeavors:

- Formation of a well-rounded community representing all pertinent stakeholders and experts in climate solutions and GHG emissions trading.
- Launching collective contributions to workshops and conferences aimed at educating on the significance of direct GHG measurements for equitable climate solutions and emissions trading.
- Collaborative creation of responses to government policy and funding proposals, co-authoring publications, and piloting projects to test the efficacy of specific methodologies.
- Future phases will involve efforts towards comprehensive recommendations or protocols, ensuring a balance across environmental, economic, financial, and regulatory aspects to achieve practical and fair climate solutions globally.

This presentation offers a progress report on the latest available tools and other developments in practical technology transfer of flux tools from academia to wider society, the latest adoption examples from FAO to the oil and gas sector, and a progress report on the latest activities by the CarbonDew Community.

12

Reduced-Cost Sensor for Direct Evapotranspiration and Sensible Heat Flux Measurements

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Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

Evapotranspiration (ET) plays a vital role in the global water cycle, moving a staggering 500,000 km3 of water annually, with 70,000 km3 occurring over land. This amount surpasses the global water demand of approximately 4,600 km3 per year. By conserving just 5-10% of ET through retention in soil, groundwater, or freshwater bodies, a significant contribution can be made towards solving the global water scarcity issue.

Accurate measurement of ET is essential for effective water management in specific areas. Unfortunately, conventional models such as potential, reference, max, equilibrium, and pan do not achieve the necessary level of accuracy, which is better than 5-10%. However, direct ET measurements using the eddy covariance method provide the required resolution. Historically, the high cost and complexity of this approach have limited its usage primarily to academic research.

To address these challenges, a new cost-effective solution for direct, automated, and real-time ET measurements has been developed. This technology extends the application of eddy covariance ET measurements beyond academia to broader research, regulatory, and commercial domains. The LI-710 sensor is a user-friendly device that measures ET, sensible heat, temperature, humidity, and air pressure every 30 minutes. It is significantly more affordable than typical flux stations, costing 5-10 times less, and consumes 3-15 times less power. Moreover, it can be easily installed and utilized by individuals with limited experience in the field.

The extensive field test results of this innovative technology will be compared with traditional higher-cost research-grade eddy covariance systems.

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Direct Flux Measurements for Immediate Social Benefits: Clear Explanations, Automated Instruments, Peer-To-Peer Data Sharing, and Weather Station-Inspired Approach

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Theme

14. Leveraging Direct Flux Measurements Beyond Academia for Real-World Applications

Abstract Text

Continental-scale research infrastructures and flux networks (e.g., AmeriFlux, AsiaFlux, ChinaFlux, ICOS, NEON, OzFlux) alongside smaller GHG flux networks and individual sites, assess CO2, CH4, and other GHG exchange, as well as evapotranspiration (ET), between ecosystems and the atmosphere.

Over four decades, these flux stations have expanded to 2100+ stationary measurement points and various campaign sites. Initially for process-level studies, they now inform long-term climate modeling.

These high-resolution measurements utilize cutting-edge hardware, significantly surpassing typical monitoring methods, commonly applied outside academia. Yet, despite their potential for measuring GHG emissions and ET, these applications rarely extend beyond academia.

Key barriers include the perceived complexity of the method, actual complexity and cost of current instrumentation and site operation, scarcity of geographic data coverage, and a lack of a comprehensive approach focused on using direct flux measurements for immediate societal benefits.

These challenges can be addressed by:

- Simplifying explanations and offering detailed guides for method understanding.
- Developing lower-cost simpler-to-use automated flux instrumentation, akin more to being a “flux sensor” than a “flux system”.
- Facilitating peer-to-peer cross-sharing to reduce data gaps and station setup costs.
- Adopting an approach inspired by current automated weather stations (AWS) feeding and tuning remotes sensing products and resulting in weather modeling and forecasting.

This presentation aims to catalyze discussions on utilizing flux measurements for practical decision-making applications to benefit society. It seeks to identify current needs, ideas, and examples for leveraging flux data in everyday decision contexts.

14

The compatibility of ICOS, NEON, and TERN sampling designs, different camera setups for effective plant area index estimation with digital hemispherical photography

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Theme

17. Best Practices in the landscape of Research Infrastructures: Cooperation, Co-location and other lessons learned

Abstract Text

Environmental monitoring networks such as the Integrated Carbon Observation System (ICOS) in Europe, the National Ecological Observatory Network (NEON) in the U.S., or the Terrestrial Ecosystem Research Network (TERN) in Australia deploy different sampling schemes for in situ measurements. We report on the intercomparison of measurements of canopy gap fraction with different digital hemispherical photography setups adopting ICOS, NEON, and TERN sampling schemes. The test was carried out at the Järvselja Radiation Transfer Model Intercomparison (RAMI) birch stand, near the Station for Measuring Ecosystem-Atmosphere Relations (SMEAR) in Estonia. Results show that spreading out sampling points that cover more of the plot is important for a good representation of the forest as a whole. NEON tower plot layout scheme may be more prone to errors in overall canopy properties estimation than ICOS or TERN due to its compact sampling layout and should always be used in conjunction with its distributed plots. Different camera setups involving different camera operators, camera bodies, lenses, and settings yield slightly varied results, and it is important to ensure that the images are taken in such a way that they would not be over- or underexposed, or out of focus. In conclusion, we always recommend carrying out intercomparison measurements with old and new cameras when devices are upgraded. Our study contributes towards establishing the uncertainty and evaluating potential error budget stemming from collecting in situ measurements using different sampling schemes and camera setups.

15

Northern European Forests' carbon balance and management disturbances: the tale of the direct flux measurements

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

Northern European Forests' carbon balance has been monitored by eddy-covariance technique (EC) for nearly three decades. Given that the majority of forests in the region are actively managed, this relentless scientific endeavor is increasingly motivated by identifying the human pressures on forest carbon sink and seeking the climate mitigation potential of alternative forest management regimes. Even though valuable site-specific findings exist, a holistic understanding of forest carbon balances especially in the context of management is missing. Accordingly, here we summarize the means and variability of annual net ecosystem productivity (NEP), gross-primary productivity (GPP) and ecosystem respiration (Re) from more than 40 Northern European temperate, hemi-boreal and boreal forests to: 1) Reveal how well the current and legacy EC-measurements represent the climatic conditions, soils and site fertility types, age and species composition and management regimes; 2) Explore the primary drivers of site-to-site and inter-annual variability, and 3) Conclude what the direct flux measurements reveal on the impacts of management practices (clear-cutting, thinning/partial harvest, fertilization) and disturbance recovery. Finally, we attempt to build a data-driven model for NEP and its components over forest rotation cycles and discuss the pathway how EC-measurements can provide support for planning sustainable forest management.

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A web-based tool for the validation of Sentinel-2 and Sentinel-3 derived bio-geophysical products against ICOS terrestrial ecosystems measurements

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Theme

17. Best Practices in the landscape of Research Infrastructures: Cooperation, Co-location and other lessons learned

Abstract Text

This study aims to demonstrate how ICOS terrestrial ecosystem sites can serve as a network for validating Earth Observation products, thus enhancing spatial and temporal coverage of validation efforts. Focusing on the current ESA optical imaging sensors, the project aims to generate a match-up dataset of Sentinel-2 and Sentinel-3 observations over ICOS ecosystem sites for easing the validation of satellite-derived bio-geophysical products. The objective is to bridge the gap between ecosystem monitoring and satellite remote sensing communities, by facilitating the uptake and exploitation of ICOS data for validation purposes. The project focuses on the validation of a subset of vegetation parameters measured within the existing ICOS network, including key terrestrial Essential Climate Variables, specifically Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) and Leaf Area Index (LAI). As a main outcome of this activity, a set of Jupyter Notebooks on the Terrascope platform is developed and shared within the satellite Cal/Val community, allowing to read the ICOS data, extract the land biophysical products of interest and match them to the corresponding satellite overpasses. Issues such as the spatial representativeness of ICOS sites, the temporal sampling of satellite acquisitions and the inclusion of in-situ uncertainties as a step towards fiducial reference measurements are explored. Statistical metrics are provided within the Notebooks to estimate the suitability of the various sites for the validation at satellite pixel size. This tool is mainly developed to foster the usage of this invaluable ensemble of in-situ reference data for satellite calibration and validation purposes.

17

Linking coastal biodiversity, carbon cycling, and climate feedback: hotspots and hot moments.

Nicolas-Xavier Geilfus[1], Kurt Spence[1], Märta Brunberg[1], Christoph Humborg[2], Joanna Norkko[1], Alf Norkko[1]

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Theme

7. Carbon Cycling along the Land Ocean Aquatic Continuum

Abstract Text

Biodiversity loss and climate change underscore the critical need for a deeper understanding of their intricate interactions. Coastal ecosystems are highly productive and dynamic in terms of carbon exchange between the ocean and the atmosphere. Due to their potential for carbon capture, those ecosystems hold significant potential as nature-based solution to mitigate climate change. Yet, their effects on carbon cycling and greenhouse gas (GHG) dynamics, including carbon dioxide (CO_2) and methane (CH_4), remain inadequately understood. This knowledge gap is compounded by substantial heterogeneity in marine biodiversity, further complicating the issue.

In response to these challenges, the CoastClim initiative aims to quantify how spatial variations in biodiversity and ecosystem state, alongside with long-term (i.e., seasonal) and short-term (e.g., marine heatwaves events) variations, trigger the occurrence of hot spots and/or hot moments for interactions between marine biodiversity and GHG dynamics in coastal environments, in the Southern Finland.

At the Tvärminne Zoological Station, we continuously measured at high-resolution seawater concentration of CO_2 and CH_4 to investigate how seasonal cycles, influencing the type and intensity of primary and secondary production, will impact the production and consumption of GHG in the water column, and thereby affect their air-sea exchange (i.e., hot moments). In August 2023, field measurements performed across a land to sea gradient highlights the presence of hotspots where changes in coastal biodiversity could directly impact the observed surface seawater concentration of GHG, ranging from 160 to 2500 µatm for CO_2 and from 20 to 470 nmol/L for CH_4.

18

Advancements in atmospheric nitrous oxide eddy covariance flux measurements

Ivan Bogoev

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Theme

18. Manufacturers' Session

Abstract Text

Nitrous oxide (N_2O) is stratospheric ozone depleting, long-lived green-house trace gas with a 100-year global warming potential 298 times greater than carbon dioxide, (IPCC, 2013). Microbial production processes in agricultural soils contribute significant portion of the total N_2O emissions. The eddy covariance (EC) technique provides a continuous landscape-scale flux estimates with high temporal resolution. The availability of mid-infrared tunable diode lasers (TDL) operating at room temperature allowed the development of high precision fast response gas analyzers suitable for the EC method. In this study we describe the design and evaluate the performance of a novel, field-deployable low-power N_2O EC system. The system consists of compact closed-path TDL absorption spectrometer with a 1 m single-pass, small volume optical cell which allows the use of low power DC pump. The effects of absorption line broadening and dilution due to water vapor are minimized using Nafion intake tube acting as water vapor permeable membrane to dry the air sample. The new N_2O EC system was deployed in manure fertilized agricultural cornfield 3 m above the canopy and was collocated with an open-path CO_2 and H_2O infrared gas analyzer and ultrasonic anemometer (IRGASON). Spectral analysis and Ogive functions demonstrated that the new EC system achieves adequate performance and excellent frequency response to measure N_2O fluxes under a wide range of meteorological conditions. Further refinements for stable and prolonged unattended operation are described.

19

Experimental investigation into the footprint of an urban canopy model in a boundary layer wind tunnel

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

As a top-down approach to quantifying the greenhouse gas emissions to the atmosphere from urban areas, the real-time measurements from ground-based monitoring stations employing the eddy covariance technique are commonly coupled with footprint functions to realize the source identification. Although several numerical modeling methods for footprints have been proposed, their reliability in urban applications is not comprehensively validated by experimental data. Besides, it is still necessary to deepen our insight into the footprint features in urban areas through experiment investigations. In this research, we conducted a wind tunnel experiment to measure the concentration and flux footprints in a block-arrayed urban canopy model located in a neutrally stratified boundary layer. The velocity and concentration were measured by an X-probe hot wire anemometer and a fast-response flame ionization detector respectively. The vertical flux was evaluated using the time series data of velocity and concentration. According to the experimental experiments, the relationship between footprint distribution and measurement positions is clarified. The footprint function was found to be unique under different wind directions and cannot be simply approximated by a plume shape. These features can be divided into local and global patterns, which highly depend on building configurations. Moreover, the turbulent contribution ratio to the total flux corresponding to each emission position was calculated. It was found that the turbulent ratio exceeds 70% near the peak of footprint in most cases, which emphasizes the importance of accurate turbulent dispersion modeling in numerical methods.

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Evaluation of the behaviour of O_2 and CO_2 above a canopy of a forest and its application to further constrain the forest carbon balance

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

The ratio between atmospheric O_2:CO_2, also called the Exchange Ratio (ER), serves as a valuable tracer for comprehending the carbon cycle at both local and global scales. We investigate the applicability of the ER, focusing on characterizing ERs of biosphere exchange. We have conducted measurements above a boreal forest in Hyytiälä, Finland, during the spring and summer of 2018 and 2019, where we measured O_2 and CO_2 mole fractions at two heights above the canopy. Integration of the observational data with a conceptual land-atmosphere model reveals that diurnal variations of ERs from single-height O_2 and CO_2 mole fractions often do not directly reflect forest exchange dynamics. Consequently, careful consideration of the time of day is essential for single-height measurements. The ERs derived from inferred surface fluxes based on the vertical gradient measurements provide a more precise representation of the processes driving the forest exchange. The observed diurnal averaged ER signal from the boreal forest, of 0.83, exhibits temporal fluctuations, challenging the commonly assumed constant biosphere ER value of 1.1. To expand on our diurnal analysis of the ER, we have integrated O_2 into the Simple Biosphere Model (SiB4) to explore temporal and spatial variations in the biosphere ERs across different ecosystems. Validation of the model is done with measurements from high-towers where O_2 and CO_2 mole fractions are measured at multiple heights. This comprehensive study aims to enhance our understanding of biosphere ER variability and its implications as a tracer in carbon cycle research.

21

Co-location of measurement sites – what does it mean and what is the added value it provides?

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Theme

17. Best Practices in the landscape of Research Infrastructures: Cooperation, Co-location and other lessons learned

Abstract Text

ACTRIS, ICOS and eLTER are distributed research infrastructures (RIs) providing data from hundreds of measurement sites spread over Europe and beyond, focusing on different components and processes of the environment. Co-location of the measurement sites of different RIs can provide scientific added value and economic savings compared to a situation where the sites are entirely separated, and this has been recognized by both the scientific community and research infrastructure funders. But what does this co-location actually mean?

From a scientific perspective it is a question of integrating data provided by different RIs and spatial continuity of the measured parameters. Flux and process measurements provide data from very small areas and cannot be extrapolated in a heterogenic environment, therefore requiring very close co-location. Measurements of atmosphere above the canopy level and especially those done via remote sensing can represent conditions and sources averaged over thousands of km^2 if the topography is sufficiently homogenous. This means that the measurement sites of different RIs can sometimes be located tens of kms apart and still provide scientific added value due to co-location and potential for up- or downscaling. It depends on the parameters and metadata included and planned use of data.

From an economic perspective co-location enables use of the same physical infrastructure (buildings, roads, electricity) and maintenance for a larger number of instruments contributing to several RIs. In this case the potential benefits require that the sites are very close to each other, and access to all instruments is agreed between host organizations.

22

Resilience of Estuarine Ecosystems to Sediment Dynamics and Climate Variabilityelevation

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Theme

15. Science communication and outreach to increase the impact of climate research

Abstract Text

Estuaries, as transitional zones between freshwater rivers and marine environments, play a crucial role in coastal ecosystems worldwide. However, they are increasingly vulnerable to the impacts of sediment dynamics and climate variability. This project aims to monitor estuarine sedimentation in correlation to sea-level rise and investigate the resilience of estuarine ecosystems in the face of these challenges.

Through a multidisciplinary approach combining field observations, remote sensing, and modeling techniques, we will assess the long-term changes in sediment deposition patterns and sea-level rise impacts on estuarine environments. Daily monitoring of sea surface temperatures will provide crucial insights into the influence of climate variability on estuarine ecosystems.

The study will focus on a specific estuarine system, employing sediment core analysis to reconstruct historical sedimentation rates and characterize sediment properties. By integrating historical data with contemporary observations, we will identify trends in sediment dynamics and their relationship with sea-level rise.

Furthermore, we will investigate the response of estuarine biota to these environmental stressors. Biological surveys will assess the abundance and distribution of key species, including benthic organisms and submerged vegetation, providing insights into ecosystem health and adaptation strategies.

Understanding the resilience mechanisms of estuarine ecosystems is essential for effective management and conservation efforts. This research will contribute valuable knowledge to inform coastal resource management practices, including habitat restoration, sediment management, and climate adaptation and control strategies. The project seeks to enhance our ability to mitigate the impacts of environmental change on coastal regions and promote the sustainable stewardship of estuarine habitats.

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Clumped isotope signatures of atmospheric CO_2 sources

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Accurately identifying sources of greenhouse gases is important in order to verify and assist in quantification and modelling of greenhouse gas fluxes. For CO_2 emissions, stable isotope measurements of carbon and oxygen are commonly utilised. The use of $\delta(^{13}C)$ and $\delta(^{18}O)$ as tracers of atmospheric CO_2 are, however, complicated by overlaps in isotopic signatures of CO_2 sources. The clumped isotope excess, Δ_{47} (which is a measure of the deviation from the statistical abundance of ^{13}C-^{18}O bonds in CO_2) can aid in the distinction of CO_2 sources, as the abundance depends on CO_2 formation temperature, rather than the abundance of elemental isotopes.

Here we aim to present measurements of Δ_{47} from a variety of locations. These include a UK cement works, which shows the influence of high temperature combustion processes; Alice Holt Forest (Surrey, UK), which is influenced by plant respiration and photosynthesis; and Weybourne Atmospheric Observatory (Norfolk coast, UK) which is situated close to the North Sea and may be influenced both by local sea-air gas exchange and urban plumes, depending on the air mass origin. Distinct differences between each site allow deriving an improved range of Δ_{47} signatures from different sources and complement information on the sources of CO_2 emissions from the other CO_2 stable isotope signatures $\delta(^{13}C)$, $\delta(^{18}O)$ and $\Delta(^{17}O)$.

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Hot Spots and Hot Moments in Greenhouse Gas (CO_2, CH_4 and N_2O) Fluxes in a Diverse Coastal Ecosystem

Märta Brunberg[1], Christoph Humborg[2,1], Alf Norkko[1,2], Aki Vähä[1,3], Marc Geibel[2], Florian Roth[2,1]

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Theme

7. Carbon Cycling along the Land Ocean Aquatic Continuum

Abstract Text

Coastal ecosystems have high rates of organic matter (OM) accumulation and can act as efficient net sinks of carbon dioxide (CO_2) from the atmosphere, which makes them suitable for nature-based climate change mitigation. At the same time, concurrent natural emissions of methane (CH_4) and nitrous oxide (N_2O) produced during OM degradation may impede the net radiative forcing benefit. Here, we simultaneously measured CO_2, CH_4, and N_2O surface water concentrations, and calculated their associated sea-air emissions, using an underway survey technique in a 28 ha semi-enclosed bay in the Baltic Sea with various vegetated and unvegetated bottom substrates during seven campaigns from October 2021 to August 2022. Bottom habitats included rocks with macroalgae, and soft sediments with or without various macrophytes, such as *Zostera marina* and *Myriophyllum spicatum*. We report net greenhouse gas (GHG) fluxes from surface waters ranging from -874.5 mg CO_{2eq} m^{-2} d^{-1} in May (net sink) to 70.9 mg CO_{2eq} m^{-2} d^{-1} in December (net source), with large temporal and spatial variability. Additionally, we show that the highest emissions generally occurred in sheltered and vegetated areas of the bay. Throughout the year, net uptake of CO_2 by vegetation was offset by 5 to 44 % by concurrent CH_4 and N_2O emissions. Coastal vegetated bays may indeed function as net sinks of atmospheric CO_{2eq} over an annual cycle, but concurrent CH_4 and N_2O emissions, and the natural heterogeneity of such fluxes should be taken into account to establish informed climate change mitigation strategies.

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International Governance of Marine Carbon Dioxide Removal: Bridging the Divide Between the Global Climate Regime and the Global Ocean Governance Regime

Roman Webb

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Theme

8. Enhancing the ocean carbon sink: the science, verification, and governance of marine-based carbon dioxide removal (mCDR)

Abstract Text

With the impacts of climate change intensifying and progress in reducing emissions continuing to lag, the parties to the Paris Agreement are increasingly looking at greenhouse gas removal as a climate change mitigation tool. Marine-based carbon dioxide removal (mCDR) has received particular attention under the Paris Agreement recently. At a meeting in late 2023, the parties to the Paris Agreement stressed "the importance of conserving, protecting and restoring . . . marine ecosystems" as carbon sinks and called for "accelerating" carbon removal. Just a few weeks earlier, however, the parties to another set of international agreements – the London Convention and Protocol – had proposed new restrictions on mCDR. In justifying the restrictions, the parties rightly noted that there is currently limited understanding of mCDR techniques, and raised valid concerns about the risks they present. The parties recognized the need for further research into mCDR but indicated that only "legitimate scientific research" should be allowed. While this approach may have theoretical appeal, in practice, determining what research is legitimate is proving difficult. There are growing concerns that restrictions adopted under the London Convention / Protocol will block research needed to determine what (if any) role mCDR might play in achieving the Paris Agreement's goals. This presentation will explore the reasons behind, and implications of, the growing disconnect between the two treaty regimes. It will also explore options for promoting greater coherence in international governance of mCDR, including the possibility of using the new High Seas Treaty to comprehensively regulate mCDR.

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MISO - Autonomous in-situ observation platform for hard-to-reach areas

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Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

MISO will develop and demonstrate an autonomous in-situ observation platform for hard-to-reach areas, such as the Arctic and wetlands overall. We are working on a new design to detect and quantify CO_2 and CH_4 fluxes, using a combination of stationary and mobile (drone) solutions. Our system will require minimum on-site intervention when deployed. In the MISO project, the AWI team is leading the development of the GHG flux chambers and leading the proof of concept for deployment in wetland and Arctic ecosystems. The new chamber design is focusing on lower cost, low weight and low energy consumption. Each self-contained chamber includes an integrated MISO sensor, self-power, and innovative communication solutions in rural areas.

27

Consequences of intense drought on CO_2 & CH_4 fluxes and evapotranspiration rates of the reed ecosystem at Lake Neusiedl

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

Wetlands with reeds (*Phragmites australis*) are widely recognized as strong carbon (C) sinks due to the high productivity of reed and its fixation in the soil. Lake Neusiedl is an internationally important wetland (Ramsar, UNESCO World Heritage Site) that had been affected by droughts since mid-2015. However, the impact of drought on reed-dominated wetlands and the contribution of Central European reed ecosystems as a source of greenhouse gases (GHG) are not well understood. The aim of this multi-year study (mid-2018 to 2022) was to investigate the drought-influenced C & water fluxes and their drivers in the reed ecosystem of this subsaline lake. We used eddy covariance technique to quantify GHG exchange between reed ecosystem & atmosphere and vegetation indices to account for reed growth.

The results showed a 76% decrease in CH_4 emissions from 9.2 g C m^{-2} a^{-1} (2019) to 2.2 g C m^{-2} a^{-1} (2022), mainly due to the falling water level and the associated drying out of the reed belt. Initially, net CO_2 emissions decreased by 85% from 181 g C m^{-2} a^{-1} (2019) to 27 g C m^{-2} a^{-1} (2021), as the reed grew into formerly water-covered areas within the reed belt. In 2022, however, net CO_2 emissions increased to twice the 2019 level due to the consequence of the sharp drop in sediment water content from 65 to 32 Vol-% in mid-2022.

Overall, drought led to a decoupling of the reed belt from the lake and turned the wetland into a strong C source.

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Carbon flux responses of Alpine ecosystems to combined future climate drivers: Exploring different climate scenarios

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

During the 21st century, alpine areas are experiencing warming above the global average, making them more sensitive to climate change, with potentially dramatic effects on the release of significant quantities of CO_2. Indeed, an expected impact of climate change is the alteration of the balance between carbon assimilation, through photosynthesis, in plant biomass and storage in soils, and its release to the atmosphere via respiration. To predict the effects of climate change on CO_2 fluxes, monoliths were collected from an alpine ecosystem (2500m a.s.l.) in the Mont Blanc area (Val Veny, Courmayeur, Italy) and transferred to the Montpellier European Ecotron (CNRS, France) for climate manipulation experiments. Monoliths were exposed to current (~ 420ppm CO_2, Control), and 2 future climate scenarios (~ 550ppm CO_2 and ~ 800ppm CO_2, according to RCP 4.5 and RCP 8.5, respectively) forecasted for 2070. The Ecotron's experimental chambers allowed to manipulate different climate variables, such as temperature, precipitation, relative humidity, radiation, and CO_2 concentration, simultaneously. To assess flux responses, measurements of gross primary productivity (GPP), ecosystem respiration (R_{eco}), and net ecosystem exchange (NEE) were performed twice a week over the summer period. While the differences in terms of fluxes between Control and RCP 4.5 were small, for the RCP 8.5 a greater GPP and more noticeable R_{eco} were observed compared to the other scenarios. Nevertheless, the NEE in RCP 8.5 showed that the alpine ecosystem could work as a sink compared to the other two scenarios, likely attributed to a substantial increase in green canopy.

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Metrological concepts applied to total alkalinity measurements in support of ocean alkalinity enhancement assessment

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Theme

8. Enhancing the ocean carbon sink: the science, verification, and governance of marine-based carbon dioxide removal (mCDR)

Abstract Text

Ocean alkalinity enhancement (OAE), a method considered for marine Carbon Dioxide Removal, involves increasing seawater alkalinity by adding alkaline substances as crushed rocks or dissolved compounds. This technique aims to increase CO_2 absorption of the ocean, but also to mitigate ocean acidification.

Prior to large-scale implementation of OAE, establishing a robust Monitoring, Reporting, and Verification system is crucial. It is advisable to monitor various variables, including total alkalinity (TA) together with at least one additional parameter of the carbonate system, to assess the OAE effectiveness. TA measurements serve multiple purposes, including computing essential carbonate chemistry parameters, quantifying background alkalinity, and confirming the efficient addition of alkalinity. Therefore, applying metrological concepts as validation of measurement procedures, uncertainty quantification, and metrological traceability, is imperative.

Although existing reference materials (RMs) for TA measurements offer valuable support to the oceanographic community, they lack complete traceability and thorough uncertainty assessment. To address this, a reference material made in artificial seawater, characterized using an SI-traceable reference method, and with rigorously quantified uncertainty is being developed. Distributing this RM alongside a natural seawater sample, as Scripps' one, could enhance the accuracy of TA results. The presentation will include results from an inter-laboratory comparison conducted on this reference material and propose traceability route, along with a preliminary estimation of the open-cell multi-step potentiometric titration measurement method of TA. The implications of this work in providing reliable TA data for assessing OAE and, more broadly, the role of NMI services in ensuring reliable ocean observation, will finally be discussed.

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Local-level CO_2 emissions and their spatial variability in two contrasting cities Helsinki and Beijing

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Comprehensive understanding of CO_2 emissions and sinks are needed to support climate actions in cities. Atmospheric observations have the challenge of measuring the total CO_2 concentration or flux providing little information on the detailed urban CO_2 flux dynamics. Here the role of bottom-up approaches in estimating the emissions strengths and spatial distributions become important as they can provide detailed information on emission and sink hotspots. In this study, the Surface Urban Energy and Water Balance Scheme (SUEWS) is used to examine the distribution of local-level direct CO_2 emissions and biogenic emissions and sinks in Helsinki (Finland) and Beijing (China). The main aims are to 1) quantify the local emissions and their spatial variability, and 2) examine the strength of the emissions and biogenic sinks as a function of urban land cover. In both cities, traffic is major contributor to the local-level emissions varying from 38% to 42%. In Beijing, emissions from local building heating were almost equal to the traffic emissions, whereas in Helsinki only minor contribution was seen due to extensive district heating. Human metabolism contributed 58% and 13% in Helsinki and Beijing, respectively showing its importance in urban carbon dynamics. Largest CO_2 sinks were seen in natural forested areas in Helsinki whereas in Beijing the forest in montane areas remained weaker sink compared to urban forests due to lower air temperatures. Vegetation within the built neighborhoods also have a significant impact on net CO_2 sinks, contributing almost half of the net CO_2 sinks in Helsinki.

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Summer greenhouse gases spatial variability from Southern Greenland Fjords to subpolar North Atlantic Ocean

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

Since the beginning of the industrial era, the atmospheric greenhouse gases (GHG) have increased continuously (around +50% for carbon dioxide (CO_2) and +150% for methane (CH_4), for the two most important), causing the current climate change. In November 2023, the World Meteorological Organization (WMO) highlighted once again there are still significant uncertainties about the carbon cycle and its fluxes, and stressed the importance to follow the non-CO_2 GHG with greater global warming potential.

The subpolar North Atlantic Ocean is a major CO_2 sink, whereas the continental shelf and fjords show more spatial-temporal variability and poor regional coverage of sea-air CO_2 flux data due to the lack of in-situ observational data. While surface seawaters are naturally supersaturated in CH_4, the Arctic region (including Southern Greenland fjords) is subject to rapid warming and, therefore, is susceptible to substantial CH_4 release into the atmosphere, further exacerbating global warming.

To improve our knowledge, it is essential to increase observational efforts to reduce uncertainties on the ocean CO_2 sink and monitoring CH_4 levels in high-latitude surface waters where changes have already been observed. To do so, we measured CO_2 and CH_4 concentrations and calculated their fluxes, in surface water during a summer cruise (July-August 2023) conducted on board the RV Belgica in the subpolar North Atlantic Ocean, between Iceland and Southern Greenland Fjords. The data were obtained using a custom-made air-water equilibration system, that was connected to the vessel's non-toxic seawater supply (equilibrator and Cavity Ring Down Spectrometer) and discrete sampling.

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URBFLUX project: Monitoring urban and peri-urban CO_2 and energy fluxes in the city of Valencia.

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

The project URBFLUX focuses on the city of Valencia as an "urban laboratory", with the general objective to provide science-based information that can be used by municipalities and other stakeholders to mitigate CO_2 emissions, reduce air pollution, and regulate temperature in the urban environment by using green infrastructure. One specific objective is to investigate the urban CO_2 emissions and sinks of the urban area of Valencia. In the frame of the project, three eddy covariance (EC) stations were deployed in 2023, in an urban area, an urban vegetated pedestrian area, and in a protected periurban area of horticultural crops. These stations will produce relevant observations on the dynamic of CO_2 fluxes in urban and peri-urban environment, but also on sensible and latent heat fluxes, to better understand the role of vegetation in regulating air temperature at both local and city scale. Another specific objective is to estimate ecosystem services provided by tree vegetation at the scale of Valencia city using the i-TREE software tool model. The outputs of the model will be air pollution removal, BVOCs emissions, gross and net annual carbon sequestration, trees sequestering most net carbon in the city, and energy savings by trees. We present an overview of the project and preliminary results from CO_2 fluxes measurements.

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Temporal and vertical variation of in-situ methane turnover from stable isotope studies at a boreal peatland

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

Boreal peatlands emit substantial amounts of CH_4 to the atmosphere. Understanding the dynamics of the co-occuring and seasonally varying processes underlying CH_4 emissions remains a challenge. Stable isotope signatures of the CH_4 in soil pore water and emitted CH_4 can provide valuable insight on these processes.

We conducted a systematic study using on-line stable isotope measurements to understand the annual cycle of CH_4 turnover in a typical boreal peatland (Siikaneva fen) in Southern Finland. We conducted continuous measurements of dissolved CH_4 concentrations and its $\delta^{13}C$ natural abundance signatures at 10, 30 and 50cm belowground. In addition, measurements at 40cm above peatland surface were used to estimate ecosystem-scale average $\delta^{13}C$ value of the emitted CH_4.

Results showed systematic differences in the vertical profiles of CH_4 concentrations and its $\delta^{13}C$ values between winter and summer. CH_4 concentrations from all the depths were higher in summer than in winter. The highest concentration of CH_4 was observed at 30cm depth. $\delta^{13}C$ values of CH_4 in peat were highest in the deeper layer and lowest in the surface layer in winter, while the opposite pattern was found in summer. As expected, the CH_4 production pathway shifted towards acetoclastic methanogenesis during the winter-summer transition. In winter, the $\delta^{13}C$ values from emitted CH_4 were higher than those from the soil indicating CH_4 oxidation, while in summer the opposite was found due to CH_4 diffusive plant transport. We observed hysteresis-like behavior between CH_4 concentration and $\delta^{13}C$ indicating time-lagged CH_4 production to soil temperature and substrate availability.

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Modelling the CO_2 transport through secondary circulations

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

The investigation of the systematic energy balance gap has indicated that a part of the energy transport is not carried out by small-scale turbulence but by so called secondary circulations, which are large eddies spanning the entire atmospheric boundary layer vertically. The share of energy transported by secondary circulations is especially large over thermally heterogeneous surfaces and cannot be captured by typical 30-minute single-tower eddy covariance measurements by definition. It is highly probable that these secondary circulations also transport other substances, such as CO_2, which results in an underestimation of the CO_2 fluxes by single-tower eddy covariance measurements. The transport through secondary circulations can be quantified as dispersive fluxes. We present a novel model that is able to predict the dispersive CO_2 flux, which is an extension of an already existing model of the dispersive sensible and latent heat fluxes. The model has been developed by combining a machine-learning approach with a large set of idealized large-eddy simulations covering different surface-heterogeneity scales and stability regimes and it can be applied to 30-minute eddy covariance measurements without additional instrumentation. The application of the models for sensible and latent dispersive heat fluxes to real-world measurements and realistic large-eddy simulations from the CHEESEHEAD19 project indicate a good agreement. Here we show that the approach is transferable to dispersive CO_2 fluxes and test the model on the realistic CHEESEHEAD19 large-eddy simulations.

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Design, operation, and insights from Zürich city's mid- and low-cost ICOS Cities CO_2 sensor network

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

A carbon dioxide (CO_2) sensor network was deployed across the city of Zürich (Switzerland) in mid-2022 as a component of the ICOS Cities project. ICOS Cities has the overall objective of quantifying CO_2 emissions in urban areas and to assess a wide range of methods to achieve this goal. The CO_2 sensor network is composed of 180 nondispersive infrared (NDIR) sensors at two broad cost points labelled mid- and low-cost. The mid-cost sensors are generally installed with inlets at roof level and are deployed with reference gases to enable the sensors to achieve very good levels of measurement performance (RMSE of less than 1.5 ppm and biases within ±1 ppm at hourly resolution). The low-cost sensors are an order of magnitude cheaper, are generally installed at street level, and their calibration instability over time, i.e., drift, is addressed with network calibration methods that utilise the trusted mid-cost sensor observations. Although the main utility of the sensor network is to provide observations for atmospheric inversion modelling systems, the sensor network itself provides value by illuminating Zürich city's CO_2 gradients and source-sink dynamics. For example, the city's CO_2 spatial gradient is between 30 and 35 ppm depending on the season, the city's regional background CO2 is highly variable, and biogenic emissions combined with very stable nocturnal boundary layer processes can drive peak CO_2 mole fractions over 700 ppm in the very early morning at some monitoring sites. The design, operation, and results of the sensor network will be further detailed and presented.

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Fossil Fuel CO_2 gradients and emissions in London observed using Radiocarbon (^{14}C) Measurements

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Urban areas accommodate over half of the global population and contribute more than 60% to greenhouse gas emissions. The increase in greenhouse gases, notably CO_2, primarily stems from fossil fuel emissions. However, accurately quantifying fossil CO_2 emissions in urban regions remains challenging due to complex and varied sources, including anthropogenic and biogenic factors, and spatiotemporal variability. Radiocarbon (^{14}C) measurements in atmospheric CO_2 provide a method to differentiate between fossil and non-fossil sources, as fossil carbon lacks ^{14}C. At Imperial College London, we conducted ^{14}C measurements to assess fossil fuel CO_2 emissions and biospheric CO_2 fluxes at three sites across London between 2022 and 2023. We used a sampling system that adsorbs CO_2 onto a molecular sieve trap after removing water, with the sampled CO_2 desorbed through heating for measurement. The measurement uncertainty is below 2‰. We find that the fossil fuel CO_2 emissions exhibited the highest levels during the winter months for all the three sites across London, whereas biospheric CO_2 exhibited the lowest values during the spring-summer seasons. The ongoing warming trend in spring enhanced the uptake of photosynthetic CO_2, leading to the most significant seasonal shift in net ecosystem CO_2 exchange.

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Leveraging In Situ Data for Climate and Environmental Policy Support

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Theme

13. In situ data for climate and other environmental services and policy support

Abstract Text

Using in situ data is essential for sustaining environmental services and guiding policy decisions in the age of rapidly increasing climate change and environmental degradation. In order to incorporate in situ data into frameworks for environmental and climate policy, this article highlights important findings and methods from the fields of Meteorology and Climate science.

This study examines the value of in situ data in improving the precision and dependability of climate models, enabling efficient environmental monitoring, and assisting with the development of evidence-based policy. It draws on my professional experience with the Nigerian Meteorological Agency. This report emphasizes the transformational potential of in situ data in solving modern environmental concerns by integrating empirical facts and best practices.

One of the main topics covered is how to incorporate in situ data into climate change mitigation.

Keywords: In situ data, Climate change, Environmental policy, Sustainability, Policy support.

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Photosynthetic leaf-level temperature response of dominant tree species in a humid lowland tropical forest of the Congo Basin

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

Tropical forests, crucial components of the global carbon cycle, are increasingly threatened by climate change. Recent studies emphasize the concerning trend of tropical tree species approaching their thermal limits, resulting in a decrease in net carbon uptake above current ambient temperatures. These findings, combined with the historically stable climate of tropical regions, raise concerns about these forests' ability to adapt to rapid temperature changes and the growing frequency of climate extremes.

Moreover, the influence of canopy position on temperature-response of photosynthesis remains poorly understood, despite its potential significance in shaping ecosystem dynamics. Variations in physiological and morphological traits across canopy layers suggest nuanced responses to rising temperatures, with implications for species distributions and forest resilience.

To address these knowledge gaps, we conducted field-based leaf chamber measurements in the Congo Basin, housing the world's second-largest tropical forest, at the CongoFlux research site [Station ID: CD-Ygb]. Leveraging the presence of an ICOS flux tower enables the comparison of our leaf-level data with ecosystem-level measurements, facilitating comprehensive analyses from individual species to ecosystem-scale processes.

Doing so, our study aims to provide the first comprehensive dataset on leaf-level photosynthetic parameters for dominant tree species in an African lowland tropical forest. By quantifying interspecific variation in photosynthetic capacity and exploring the influence of plant guilds, species, and vertical canopy position, we seek to enhance our understanding of forest dynamics and resilience to temperature changes.

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Advances and challenges of Solar-Induced chlorophyll Fluorescence (SIF) in understanding Arctic-Boreal carbon uptake across spatial-temporal scales: A review

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

Solar-Induced chlorophyll Fluorescence (SIF), a good proxy for vegetation CO_2 uptake, has been broadly utilized to assess vegetation dynamics and carbon uptake at the global scale. However, the full potential and limitations of SIF in the Arctic-Boreal region have not been explored. Therefore, this presentation summarizes a recently published review paper (doi: 10.1007/s40641-024-00194-8) of the latest insights into Arctic-Boreal carbon uptake through SIF analyses, underscoring the advances and challenges of SIF in solving emergent unknowns in this region. We will present evidence that cross-scale SIF measurements complement each other, offering valuable perspectives on Arctic-Boreal ecosystems, such as vegetation phenology, carbon uptake, carbon-water coupling, and ecosystem responses to disturbances. By incorporating SIF into land surface modeling, the understanding of Arctic-Boreal changes and their climate drivers can be mechanistically enhanced, providing critical insights into the changes of Arctic-Boreal ecosystems under global warming. While SIF measurements are more abundant and with finer spatiotemporal resolutions on the global scale, it is important to note that the coverage of these measurements is still limited and uneven in the Arctic-Boreal region, which addresses the importance of fostering a SIF network providing long-term and continuous measurements across spatial scales.

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TOWARDS 2060 CARBON NEUTRALITY: AIR POLLUTION AND HEALTH CO-BENEFITS OF CLIMATE CHANGE MITIGATION OF THE GBA

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Theme

15. Science communication and outreach to increase the impact of climate research

Abstract Text

Climate change and air pollution are interrelated. Climate mitigation could bring multiple benefits, among which air pollution-related health cobenefits are the most important. With its carbon emissions expected to peak around 2030, the Chinese government strives to reach the ‘carbon neutral’ goal for the whole nation by 2060. Guangdong-Hong Kong-Macau Greater Bay Area (GBA) is now the biggest rapidly developing economic and industrial region in China, with a population of 22 million. Its intensive industry and human activities have a significant influence on the national economy but at the cost of local air quality and intensifying climate change with substantial greenhouse gas (GHG) emissions. Local municipal and provincial governments of the GBA have pledged recently to achieve carbon neutrality by 2060. Concrete measures and pathways to achieve this ambitious target have yet to be made. Thus, it is important to explore the potential climate change mitigation pathways to 2060 carbon neutrality and to have a comprehensive assessment of air quality and health co-benefits of the implementation of climate change mitigation pathways for developing the optimised climate policy and a collective action plan for the local governments of the GBA to reach a win-win result. The study aims to link the climate change mitigation, air pollution reduction and health co-benefits together to explore the optimal pathways to achieve the targeted carbon neutrality in 2060.

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The ocean gliders capacity to estimate the air-sea CO2 flux: from machine learning tools to innovative sensors

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Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

The ocean is a major sink of anthropogenic CO2 (Friedlingstein et al., 2020). Estimates of the ocean's carbon sink are derived from global ocean biogeochemical models (Hauck et al., 2020) and reconstructions based on data concerning surface ocean partial pressures of CO2. The Surface Ocean CO2 Atlas (SOCAT) (Bakker et al., 2016) primarily relies on data obtained from underway sampling systems aboard voluntary observing ships. However, the limited coverage of data and the absence of observations throughout the entire seasonal cycle pose challenges to mapping methods, resulting in noisy reconstructions of surface ocean pCO2 (Denvil-Sommer et al., 2019). In response, the emergence of deep learning methods offers an alternative for predicting carbonate system variables (Sauzède et al., 2016; Fourrier et al., 2020). Nonetheless, fostering the advancement of robust and dependable technologies is imperative for enhancing observing systems. In this context, the European project GEORGE (grant 101094716) aims to develop new technologies to improve ocean observations that will represent the next level of long-term autonomous ocean observations. It will improve the coverage, continuity and spatio-temporal resolution of marine observations based on a variety of platforms operated by three ERICs (EMSO, ICOS and Euro-Argo). We will focus here on the development and integration of new sensors for carbonate system measurements (TA, TC, pH and pCO2). Of particular interest will be ocean glider-operated measurements and pCO2 and pH sensors in the Ligurian Sea, accompanied by acoustic measurements for better estimation of wind speed, an important parameter in CO2 air-sea flux calculations.

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Surface CO_2 system dynamics along the western Mediterranean Sea based on high-frequency measurements from a Volunteer Observing Ship.

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

The spatio-temporal variations in the surface CO_2 system along the western boundary of the Mediterranean Sea is evaluated. A high-resolution physicochemical dataset spanning 5 years (2019-2024) was built through automatically underway monitoring lead by the Surface Ocean Observation Platform aboard the Volunteer Observing Ship MV JONA SOPHIE (ICOS SOOP CanOA-VOS). The ongoing warming of the surface Mediterranean was documented based on observations in this area. The sea surface temperature (SST) increased by 0.38±0.05 ºC yr^{-1} in the Alboran Sea and 0.30±0.04 ºC yr^{-1} along the eastern Iberian margin (p-values<0.01), which represent an acceleration in warming of 87.9% and 78.0%, respectively, compared to 2000-2019. These rates were found to be led by a rapidly increment in SST during summer, which contributed to modify the temporal evolution of the surface CO_2 fugacity ($fCO_{2,sw}$) and pH. Its interannual rates of change were 4.8 ± 0.6 µatm yr^{-1} and -0.005±0.001 units yr^{-1} in the Alboran Sea and 5.2 ± 0.4 µatm yr^{-1} and -0.006±0.001 units yr^{-1} in the eastern Iberian margin (p-values<0.01). The rise in $fCO_{2,sw}$ was governed by SST fluctuations (contributing by 59.1-63.0%) and compensated by variations in total inorganic carbon (27.9-31-6%). Both subregions behaved as a net atmospheric CO_2 sink (average values -0.80±0.01 and -0.57±0.01 mol m^2 yr^{-1}). However, warming is favouring the outgassing during late summer and reducing by a 50% the annual uptake of CO_2 from the atmosphere during the studied period (-0.52 mol m^2 yr^{-1} in 2023 *versus* -1.02 mol m^2 yr^{-1} in 2019).

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Shoots of mature European beech as important sinks for atmospheric nitrous oxide (N_2O)

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Tree stems are known to emit but also consume nitrous oxide (N_2O) from the atmosphere. Even though tree leaves dominate the tree surface area, they have been entirely excluded from field N_2O flux measurements, and their role in forest N_2O exchange is still unknown. We investigated the contribution of leaf fluxes to the forest N_2O exchange. We determined the N_2O exchange of stems and shoots (i.e. terminal branches including leaves) of mature European beech (*Fagus sylvatica*), and adjacent forest floor in a typical temperate upland forest in Southern Germany, using static chamber systems, portable greenhouse gas analyser and scaffold towers to reach the top of tree crowns. The beech stems, and especially the investigated shoots acted as net N_2O sinks (-0.254 ± 0.827 µg N_2O m^{-2} stem area h^{-1} and -4.54 ± 1.53 µg N_2O m^{-2} leaf area h^{-1}, respectively), while the forest floor was a net source (2.41 ± 1.08 µg N_2O m^{-2} soil area h^{-1}). Our pioneering study revealed a key mechanism at the net forest ecosystem N_2O exchange: never-studied tree shoots can be substantial N_2O sinks. Our results clearly show that excluding tree leaves from forest N_2O flux measurements could lead to substantial uncertainties in the total N_2O exchange between trees and the atmosphere, altering global forest greenhouse gas flux inventories.

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Flux measurements of carbon monoxide by eddy covariance over two pristine wetlands in high latitudes

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

Carbon monoxide (CO) plays a major role in atmospheric chemistry, being the largest sink of hydroxyl radical OH, which is the key oxidant in the atmosphere and determines the distributions of many other chemical species, including methane and ozone. Additionally, CO serves as an energy source for various soil microbes, playing a significant role in the carbon cycle.

In this study, we present the first eddy covariance time series of CO fluxes measured over two pristine wetlands. The study sites, Siikaneva fen in southern Finland and Abisko-Stordalen Palsa-bog in northern Sweden, are both classified as ICOS class 2 Ecosystem Stations. Measurements were conducted during the years 2019 and 2022-2023, respectively.

We observed systematic diurnal and seasonal cycles in the fluxes, with emissions during the daytime and near-zero fluxes or uptake during the night-time at both sites. Both sites were net CO sources during the snow-free periods, with greater spatial and temporal variability in fluxes observed in Stordalen than in Siikaneva. The CO emissions were driven by radiation and temperature, related to photo- and thermal degradation of organic matter. In Stordalen systematic soil consumption was observed in nighttime fluxes, whereas consumption was not observed in Siikaneva. The consumption in Stordalen was higher in the drier part of the mire, likely controlled by differences in soil properties.

Despite the relatively small amount of carbon released as CO from wetlands, understanding the CO flux dynamics plays a crucial role in understanding soil processes and atmospheric chemistry.

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Addressing challenges in representing inter-annual variability of gross primary productivity fluxes using robust empirical and theory-based models

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Terrestrial vegetation is crucial in the carbon cycle, primarily for mediating atmospheric CO_2 fluxes through photosynthesis. The inter-annual variation (IAV) of gross primary production (GPP) is highly correlated with peak GPP frequency in diurnal cycles, yet biogeochemical models often fail to simulate these peaks. Here, we compare a light use efficiency (LUE) model and an eco-evolutionary optimality-based P-model to simulate the IAV of GPP. Both models estimate GPP at sub-daily scale, and are optimized for each site-year, site, plant functional type, and globally, followed by an evaluation at different temporal resolutions across 198 eddy-covariance sites of diverse climate-vegetation types. Hourly model (site-year optimization) evaluations show significantly higher performance (Nash-Sutcliffe efficiency, viz. NSE ≥ 0.6 for 93% and 86% of sites for LUE and P-model respectively) compared to yearly aggregated evaluations (NSE ≥ 0.6 for 44% and 29% of sites for LUE and P-model respectively). The LUE model performs better than P-model as we optimize parameters in temperature, vapor-pressure deficit functions and consider the cloudiness effects. Further investigation of the role of soil moisture stress reveals that it substantially improves the P-model's (which already considers acclimation of parameters) performance (from an NSE of -0.94 to 0.93) in simulating annual average GPP per site-year. For both models, optimized parameter values vary more across the sites than in the site-years. Moreover, we analyze the role of data versus model epistemic uncertainty in estimating the IAV of GPP. Our model-data-integration experiments reveal current models' limitations in capturing the IAV of carbon flux and guide their improvements.

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Evaluation of atmospheric CO_2 transport across scales from cities to continents

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

To support the development of the new European anthropogenic CO_2 emissions Monitoring and Verification Support capacity (CO2MVS) within the Copernicus programme of the European Commission, the EU-funded Carbon Atmospheric Tracer Research to Improve Numerical schemes and Evaluation (CATRINE) project aims to evaluate and improve the numerical schemes for tracer transport in CO2MVS and more widely in the Copernicus Atmosphere Monitoring Service (CAMS). This will be done by using very high-resolution models at sub-kilometre resolutions to assess and improve the transport processes at city scales relevant to the ICOS Cities project and global models (at resolutions of 100 km or smaller) that provide information of the large-scale transport relevant for the global carbon budget and boundary conditions to the local very high-resolution limited-area models. The project will define protocols and metrics for evaluating tracer transport models at both global and local scales and provide links between the two scales by sharing boundary conditions and city-scale observations to evaluate the capability of both local and global systems to simulate atmospheric CO_2 signals from anthropogenic emissions. Test beds based on field campaign case studies will be developed, along with suitable metrics for tracer transport evaluation with a range of tracers and observations from field campaigns and operational networks like ICOS. These metrics will be employed in the operational CO2MVS to evaluate the implementation of new transport model developments, characterise transport accuracy and representativity in data assimilation, and provide a quality control stamp of tracer transport accuracy.

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Higher global gross primary productivity under future climate with more advanced representations of photosynthesis

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Gross primary productivity (GPP) is the key determinant of land carbon uptake, but its representation in terrestrial biosphere models (TBMs) does not reflect our latest physiological understanding. We implemented three empirically well supported but often omitted mechanisms into the TBM CABLE-POP: photosynthetic temperature acclimation, explicit mesophyll conductance, and photosynthetic optimization through redistribution of leaf nitrogen. We used the RCP8.5 climate scenario to conduct factorial model simulations characterizing the individual and combined effects of the three mechanisms on projections of GPP. Simulated global GPP increased more strongly (up to 20% by 2070-2099) in more comprehensive representations of photosynthesis compared to the model lacking the three mechanisms. The experiments revealed non-additive interactions among the mechanisms as combined effects were stronger than the sum of the individual effects. The modeled responses are explained by changes in the photosynthetic sensitivity to temperature and CO_2 caused by the added mechanisms. Our results suggest that current TBMs underestimate GPP responses to future CO_2 and climate conditions.

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The AmeriFlux Management Project: Overview and the Year of Remote Sensing

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Theme

17. Best Practices in the landscape of Research Infrastructures: Cooperation, Co-location and other lessons learned

Abstract Text

AmeriFlux is a network of sites and scientists measuring ecosystem carbon, water, and energy fluxes across the Americas using eddy covariance techniques—and the many scientists who use these data. The US Department of Energy funded AmeriFlux Management Project (AMP, ameriflux.lbl.gov) aims to enhance the value of AmeriFlux for Earth system modeling, terrestrial ecosystem ecology, remote sensing, and many other fields. AMP has teams focused on four tasks: Technical support and QA/QC, Data support and QA/QC, Core site support, and Outreach. The network continues to grow. In April 2024, AmeriFlux registered its 660th site. We make 3,426 site-years of flux/met data, from 491 sites, publicly accessible. These data are used by a large community of scientists and practitioners around the world. To maintain a high level of service, AMP invests in new data capabilities and is pioneering a new mode of evaluating each site's data quality (e.g., remote data "visits" and mini workshops). We also benefit from productive partnerships. For example, the National Science Foundation (NSF) funded NEON's 47 AmeriFlux sites make it the single largest network-within-the-network. We co-develop data standards and products with the ICOS ETC. We work closely with the NSF-funded FLUXNET-Coop, which co-sponsors workshops, builds early career resources, and strengthens international connections among flux networks. This poster will highlight some of these recent activities; ongoing initiatives for remote sensing and for urban fluxes; and special offerings for scientists, such as the Rapid Response Systems (loaner eddy flux systems for urban environments and other research opportunities).

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Enhancing Greenhouse Gas Analysis: Evaluating the Picarro Gas Autosampler for Discrete Gas Sample Measurements

Keren Drori, Joyeeta Bhattacharya, Magdalena Hofmann, Jan Woźniak, Jinshu Yan, Tina Hemenway

Picarro, Santa Clara, USA

Theme

18. Manufacturers' Session

Abstract Text

The greenhouse gas research community is experiencing a growing demand for automated solutions to measure greenhouse gas concentrations in small discrete gas samples. However, existing solutions often come with high initial and maintenance costs, are complex to deploy and maintain, and are impractical for fieldwork. With advancements in technology on the horizon, there is increasing anticipation for the forthcoming Picarro Gas Autosampler in combination with Picarro analyzers featuring higher flow rates (>200 scc/m), such as the G2508. This report aims to explore the compatibility, efficiency, and advantages of the Picarro Gas Autosampler with Picarro Greenhouse Gas (GHG) Concentration analyzer G2508. Our experiments demonstrate excellent precision and accuracy in discrete gas sample measurements. Additionally, we investigate linearity in dilution factors and assess memory effects and variability across different gas species (e.g., comparing CO_2 vs N_2O). Furthermore, this report provides recommendations on methods and best practices for discrete gas sample measurements. In summary, the Picarro G2508 (or other GHG analyzers) in conjunction with the anticipated Picarro Gas Autosampler presents an appealing, cost-effective, and simpler alternative to gas chromatographs or similar solutions currently available.

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Advancing Greenhouse Gas Isotopic Measurements: Evaluating the Compatibility and Efficiency of Picarro Gas Autosampler with Picarro Isotopic Analyzers

Keren Drori, Joyeeta Bhattacharya, Magdalena Hofmann, Jan Woźniak, Jinshu Yan, Tina Hemenway

Picarro, Santa Clara, USA

Theme

18. Manufacturers' Session

Abstract Text

The greenhouse gas research community faces a growing demand for automated solutions tailored to isotopic measurements of greenhouse gases (e.g., isotopic CO_2/CH_4). Traditional solutions often entail significant initial and maintenance costs, intricate deployment and maintenance processes, and limited fieldwork adaptability. Anticipating this challenge, the Picarro Gas Autosampler is poised to attract growing interest for its anticipated compatibility with Picarro isotopic Carbon analyzers featuring low flow rates (<50 scc/m), promising efficient isotopic measurements. This report delves into the compatibility, efficiency, and advantages of the Picarro Gas Autosampler when paired with the Picarro G2201-i analyzer. Our experiments showcase remarkable precision and accuracy in isotopic measurements of greenhouse gases. Additionally, we explore factors such as linearity in dilution factors and characterize memory effects and variability across different gas species (e.g., comparing CO_2 vs CH_4). Moreover, the report offers practical recommendations on methods and best practices for conducting isotopic measurements of greenhouse gases. In summary, the Picarro Gas Autosampler, when combined with the Picarro G2201-i analyzer, emerges as a compelling, cost-effective, and user-friendly solution for isotopic measurements of greenhouse gases, offering a distinct advantage over traditional alternatives.

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Unlocking Insights: Evaluating Simulated CO_2 Over Europe Through Aircraft Observations and Error Apportionment

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Inverse modeling is pivotal in inferring surface-atmosphere exchange of CO_2 based on atmospheric observations of CO_2 concentration. However, uncertainties in inversion estimation, including emission accuracy, spatial-temporal resolution, and reliability of the transport scheme are challenges which should be addressed. Quality assessment and uncertainty decomposition are crucial tasks in greenhouse gases modeling, requiring verification and comparison studies with independent observations, which ultimately anchor the reality.

The main objective of this study is to benchmark and characterize uncertainties within the retrieval chain of CO_2 estimated by the CarboScopo Regional inversion (CSR) and CAMS, employing aircraft observations from both commercial flights and dedicated research aircraft. Moreover, the research focuses on decomposing the mismatch between observed and modeled CO_2 concentrations into distinct error vectors, aiming to apportion the strength of uncertainties associated with each vector. The outcomes of this study strongly indicate that there is a compelling need for enhancements in the parameterization of dynamics to elevate the performance of the CSR model. The observed results underscore the influence of these specific model components on the accuracy and reliability of CO_2 estimates within the regional domain. Our study shed light on the uncertainty of CO_2 estimated over Europe and reveals significant findings.We observed systematic underestimations in CO_2 concentrations within the planetary boundary layer height, indicating deficiencies in the model's representation, particularly in fossil fuel emissions and boundary layer dynamics. Specifically, our analysis highlights that dynamics account for over 60% of the CO_2 mismatch in the CSR model, with emissions contributing 28% to this discrepancy.

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Biodiesel, Chlorella and Decarbonization industry

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Theme

18. Manufacturers' Session

Abstract Text

Due to the declining fossil fuel resources as well as the need for an alternative source of biodegradable source of energy, biodiesel has a great advantage over conventional fuel due to its low content of particulates. This study investigated the production and characterization of biofuels produced from the fresh water microalgae; Chlorella vulgaris. The goal of our project is to create a technology at the national level within the framework of the My Climate project, which involves increasing the volume of biomass produced by microalgae, which will contribute to the adoption of biofuel (biodiesel) as an alternative energy source and its commercial development. Within the framework of our project, microalgae (chlorella) is considered as a raw material for biofuel. For the maximum efficiency of such fuels, a high growth rate of plant biomass is required. Chlorella is an ideal raw material in this regard, that is, an active producer of biomass - with a high percentage of proteins, fats, carbohydrates, vitamins... In total, more than 650 substances are concentrated in it, the content of which is much higher than the content of meat, milk, vegetables and fruits. Materials and Methods: Water was sampled from Sharada industrial run-off within Kano metropolis for isolation and identification of algal species. Microalgae have the potential to become the primary source of biodiesel, catering to a wide range of essential applications such as transportation. This would allow for a significant reduction in dependence on conventional petroleum diesel.

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Optimizing spatial resolution in landcover classification for accurate methane emissions estimates in Arctic and Boreal regions.

Joshua Hashemi[1], Aleksi Räsänen[2,3], Tarmo Virtanen[4], Sari Juutinen[5], Annett Bartsch[6], Laura Chasmer[7], Guido Grosse[1], McKenzie Kuhn[8], Mark Lara[9], Miska Luoto[4], Pekka Niittynen[4], David Olefeldt[10], Anna Virkkala[11], Carolina Voigt[12,13], Claire Treat[1]

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

Quantifying methane emissions from Arctic and Boreal wetlands is critical for constraining uncertainty in the global methane budget. However, current estimates exhibit considerable variability, in part, due to challenges in accurately mapping wetland distribution and type. Here, we investigate the influence of the spatial resolution of landcover classification maps on regional methane flux estimates at several locations across the Arctic and Boreal. Utilizing high-resolution landcover classification maps (<2.5 m) and chamber-based methane flux measurements, we estimate regional methane emissions at various spatial resolutions to show how emission estimates vary as a function of landcover classification pixel size. Our results show regional estimates are most accurate at spatial resolutions of ≤25 m, with coarser resolutions yielding significantly less reliable estimates. Fragmented wetlands, in particular, may be misrepresented, leading to the underestimation or misallocation of methane relevant landcover classes. Additionally, we highlight the significance of wetland type, showing that fens are more sensitive to misrepresentation due to coarse resolution than bogs or wetlands in general. Current wetland mapping products often overlook smaller wetlands, leading to inaccuracies. Findings emphasize the need to use landcover classification maps with the appropriate thematic and spatial resolution to accurately represent those landcover types that are important for methane dynamics. These insights have implications for reconciling top-down and bottom-up approaches and deepening our understanding of methane dynamics in the context of a changing climate.

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Greenhouse Gas Data assimilation using ICOS observation data for the ITMS project

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

For the purpose of observation based CH4 emission verification, we develop a data assimilation system for the project Integrated greenhouse gas monitoring system for Germany (ITMS).
Employing the numerical weather model ICON and its aerosol and trace gas (ART) extension, three-dimensional CH4 model fields are constructed from given prior CH4 emissions over Europe and CH4 initial and boundary concentration provided by Copernicus.
To pull the modelled fields closer to reality, 3D-Var and ensemble based EnVar data assimilation methods are used to combine modelled CH4 fields with ICOS station observations resulting in a CH4 analysis.
The added value of the CH4 analysis can be shown by comparing statistical errors of the modelled fields and of the analysis on observation stations independent of the data assimilation or in different measurement heights.
The implementation is efficient and is based upon systems of the DWD operational data assimilation.

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Long-term CO_2 flux measurements from an intensively managed temperate grassland

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Grassland ecosystems cover about 40% of the global land area (excluding Greenland and Antarctica) and serve a unique role in the global carbon (C) cycle. The net CO_2 uptake in managed grasslands is substantially influenced by climate conditions, accompanied by interactions with land management practices. With the eddy covariance (EC) technique, the net ecosystem exchange (NEE) of CO_2 can be directly measured. NEE represents the balance between two different ecosystem processes: gross primary production (GPP; amount of CO_2 assimilation through photosynthesis), and ecosystem respiration (Reco; amount of CO_2 released via plant and soil respiration).

This study aims to assess the dynamics of CO_2 fluxes at Chamau (CH-CHA as part of Swiss FluxNet), an intensively managed temperate grassland in Switzerland. Using machine learning approaches for 19 years (2005-2023) of EC flux, meteorological, and management data, our objectives are (1) to identify key drivers of GPP and Reco at different time scales (i.e., daily, seasonal, annual), (2) to investigate changes in grassland regrowth after management events (i.e., mowing, grazing, fertilization, sward renewal), and (3) to examine the ecophysiological responses (e.g., water use efficiency) to both climate change and management practices. Our results can provide further insights to help optimize grassland management practices to increase sward productivity and develop mitigation strategies for current and future climate risks.

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Flux ratios of CO2, CO, and NOx: an inter-city comparison between Paris and Zurich using urban tall-tower eddy covariance

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

In-situ measurements of urban greenhouse gas (GHG) emissions play a critical role in quantifying cities' contributions to regional and global emissions and are a key tool in the validation of city emission inventories and models. Cities are also complex environments containing a multitude of anthropogenic emission sources such as traffic, residential heating, and industrial production. Correct sectoral attribution of urban GHG emissions is necessary to monitor emission reduction efforts, compare against emission inventories, and separate anthropogenic from biogenic emissions.

As part of the ICOS-Cities (PAUL - Pilot Application in Urban Landscapes) project, tall-tower urban eddy covariance (EC) systems were installed in both Paris, France and Zurich, Switzerland. Use of a high-frequency multi-species gas analyser (MGA7, MIRO Analytical, Switzerland) enabled simultaneous measurements of CO_2, CO, CH_4, NO_x, N2O, and H_2O fluxes. EC measurements provide gas fluxes which integrate all emission sources and sinks within the measurement footprint. By examining the ratio of these gas fluxes in combination with a spatially-resolved emission inventory within the EC footprint, one may validate or improve the emission inventory.

We present eight months of EC flux ratios from Zurich (August 2022 until March 2023) and six months of EC flux ratios from Paris (January 2024 to June 2024). We investigate what we can learn from the differences in flux ratios between the two cities, as well as discuss the challenges and potential of using multi-species EC measurements to separate urban GHG emission sources.

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Refining the Global Picture: the Impact of Increased Resolution on CO_2 Atmospheric Inversions using OCO-2 XCO_2 retrievals

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

The threat posed by the increasing concentration of carbon dioxide (CO_2) in the atmosphere motivates a detailed and precise estimation of CO_2 emissions and absorptions over the globe. This study refines the spatial resolution of the CAMS/LSCE inversion system, achieving a global resolution of 0.7° latitude and 1.4° longitude, or three times as many grid boxes as the current operational setup. In a two-year inversion assimilating the midday clear-sky retrievals of the column-average dry-air mole fraction of carbon dioxide (XCO_2) from NASA's second Orbiting Carbon Observatory (OCO-2), the elevated resolution demonstrates an improvement in the representation of atmospheric CO_2, particularly at the synoptic time scale, as validated against independent surface measurements. Vertical profiles of the CO_2 concentration differ slightly above 22 km between resolutions compared to AirCore profiles, and highlight differences in the vertical distribution of CO_2 between resolutions. However, this disparity is not evident for XCO_2, as evaluated against independent reference ground-based observations. Global and regional estimates of natural fluxes for 2015-2016 are similar between the two resolutions, but with North America exhibiting a higher natural sink at high-resolution for 2016. Overall, both inversions seem to yield reasonable estimates of global and regional natural carbon fluxes. The increase in calculation time is less than the increase in the number of operations and in the volume of input data, revealing greater efficiency of the code executed on a Graphics Processing Unit. This allows us to make this higher resolution the new standard for the CAMS/LSCE system.

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Towards regional CH_4 inversions with ICON-ART assimilating satellite TROPOMI data over Europe

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Inverse modeling is a top-down technique which utilizes atmospheric observations to infer greenhouse gas (GHG) emissions. With this application in mind, satellite retrievals of GHGs are an attractive data source due to their dense spatial coverage compared to typically sparse surface networks. This study aims to assimilate satellite data at high resolution to independently locate and quantify GHG sources and sinks, aiding carbon budget studies and policymakers. The work also serves to develop the groundwork for the development of Germany's Integrated GHG Monitoring System (ITMS).

We couple the numerical weather prediction and atmospheric transport model ICON-ART with an Ensemble Kalman Filter (EnKF) based inversion system, using the CarbonTracker Data Assimilation Shell (CTDAS). Targeting total CH_4 fluxes over Europe, we use ccolumn-integrated methane measurements ($XCH_{4)}$ from the TROPOspheric Monitoring Instrument (TROPOMI). Prior anthropogenic emissions are taken from the CAMS-GLOB-ANT_v4.2 inventory, while natural sources are included as well from CAMS-GLOB-BIO_v3.1.

A synthetic study conducted for June 2018, demonstrates the system's ability to capture prescribed spatial patterns in emission fields, using pseudo-observations from satellite retrievals with realistic coverage. CH_4 fluxes were retrieved at 0.25° x 0.25° resolution, and prior emissions were scaled to optimally fit the measured values. Real observations are then assimilated, providing emission estimates and their associated uncertainties.

This study showcases the potential of satellite retrievals in inverse modeling, enabling us to extend its application to other GHG species, and serving as preparation for the Copernicus Anthropogenic Carbon Dioxide Monitoring (CO2M) mission.

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Addressing PhenoCam supply chain limitations with low cost (DIY) drop-in replacements

Koen Hufkens

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Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

PhenoCams provide a critical vegetation monitoring services, providing information on the state of the vegetation throughout the seasons with conventional (RGB and infrared) images. However, the deployment of PhenoCams has recently been limited due to post-COVID supply chain issues and a shortage of the recommended StarDot SC5 model (used in the EU/US PhenoCam networks). These supply chain issues have highlighted a weakness in our hyper-connected economies and the over-reliance on hardware availability and just-in-time value chains, which might not be sustainable from a practical and environmental perspective.

Here, I present two solutions to PhenoCam related hardware supply chain issue. First, I introduce the successor of the StarDot SC5 camera, the StarDot Live2 camera and the automated setup through the Phenocam Installation Tool (PIT v2). This setup will supersede the old StarDot SC5, which is no longer available from the vendor.

https://github.com/bluegreen-labs/phenocam_installation_tool_v2

Second, I provide an open hardware drop-in replacement for default PhenoCam solutions based around system on a chip (SoC) hardware. Our setup serves as low cost and highly redundant solutions in case of budgetary or hardware availability constraints, which can be repurposed for scientific outreach and educational projects. These open hardware solutions are built around 3D printed housings (support structures) and off-the-shelve components, allowing for the use of various vendors, or hardware configurations.

https://bluegreenlabs.org/post/bluegreen-labs-phenocam/

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Potential for coupling TIR/SWIR satellite sounders for wildfire research: CO from 2020-2023 megafires.

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

TIR sounders (MOPITT, AIRS, IASI, etc.) detect outgoing thermal radiation from the Earth, while SWIR instruments (GOSAT, TROPOMI, etc.) use solar radiation reflected and/or scattered from the surface or clouds. Both types provide the total column number of molecules (in molec/cm2) or VMR averaged over the entire depth of the atmosphere (in our case Xco). A fundamental limitation of TIR data is the low sensitivity to PBL. SWIR probes have the same height sensitivity in clear sky conditions. Combining these data on a daily basis opens up opportunities for studying gas concentrations in the lower troposphere. This report provides an analysis of the evolution of CO in the middle and lower troposphere from the onset of forest fires to the process of CO dissipation after the end of the fire.

Megafires occurred in Australia in the summer of 2019/2020, in Siberia in 2021 and in Canada in 2023. According to the global database GFED4c, all of these events produced record emissions of CO, CO2 and CH4,. The Xco differential measured by the TROPOMI and AIRS instruments clearly indicates the accumulation of pyro-CO in the lower troposphere and the rise of polluted air upward over time. The dispersion process occurs in both the lower and middle troposphere, but long-range transport predominates in the middle troposphere, where AIRS sensitivity is quite high. This technique could potentially be greatly improved by including specific averaging kernels for the TIR and SWIR cases, as well as a priori.

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Identifying hotspots of greenhouse gas emission from drained peatlands in the European Union

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Greenhouse gas emissions (GHG) emissions from drained peatlands in Europe contribute substantially (almost 8%) to the total EU anthropogenic GHG emissions. Current European-scale monitoring of these emissions lacks high-resolution spatial data, and individual countries differ with respect to data quality (e.g., lacking wall-to-wall reporting) which hinder integrated and effective mitigation policy implementation.

Part of the PRINCESS project, we present the first detailed land use distribution map for EU peatlands (plus several Non-EU countries), the first map on GHG emissions and a map on GHG emission hotspots. In our analysis we combined peatland distribution land use and drainage maps. Our results show that undrained peatlands and Forest Lands are wide-spread at high latitude whereas Grasslands and Croplands are most prominent around latitude 50°-55°. We identified three main hotspots in the North Sea region: northeastern Ireland, western Netherlands, and northwestern Germany, collectively responsible for 20% of drainage and land use related emissions from European peatlands, over just 8% of the total peatland area.

The study emphasizes, that mitigating emissions from European drained peatlands is crucial for achieving climate goals. It reveals substantial underestimation of emissions in current National Inventory submissions (NIS) to the UNFCCC, amounting to 120-146 Mt $CO_{2\text{-}e}$ annually on the EU+ scale, demanding a reassessment of policy measures. Policy instruments implementing and monitoring measures to reach EU's zero emission within LULUCF sector need to be peatland specific and peatland emission reporting methodology should be regularly validated.

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An Improved Analyzer for High-Precision and Low-Drift N_2O/CO Ambient Monitoring

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Theme

18. Manufacturers' Session

Abstract Text

Recognized by their critical contributions to greenhouse gas emissions, N_2O and CO have recently risen to the focus for ambient monitoring, where high precision and low drift specifications are both essentially desired to ensure data integrity for long term measurements. In response to the growing needs of the monitoring community, Picarro has launched a new N_2O/CO analyzer – PI5310 that integrates our renowned mid-infrared laser-based cavity ring-down spectrometry technology with significant software and hardware enhancements, as well as sought-after new features to better serve the remote monitoring use cases. This improved analyzer will continue to provide simultaneous real-time ambient N_2O and CO measurements, and with much improved precision and drift performance which will be reviewed in detail in this paper. Additionally, to further explore the measurement capability and comprehensively utilize its spectroscopy potential, the PI5310 analyzer is set up alongside the CO_2 and CH_4 measurements by a Picarro G2401 analyzer to characterize its performance in $^{13}CO_2$ applications, with the experimental evaluation results also summarized and discussed in this paper.

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Atmospheric variability of carbon dioxide and methane at the Lamezia Terme (Southern Italy) WMO/GAW regional station

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

With increasing concern over climate change and its environmental impacts, effective greenhouse gases (GHGs) control strategies are of pivotal importance. The use of models (*i.e.*, STILT Stochastic Time Inverted Lagrangian Transport), statistical techniques, and experimental data analysis provide valuable tools for quantifying emissions and identifying trends of GHGs. The Mediterranean basin is considered a global hotspot for air-quality and climate change. Since 2015, the World Meteorological Organization/Global Atmosphere Watch (WMO/GAW) permanent observatory of Lamezia Terme (LMT) in Calabria, Southern Italy, has been continuously measuring GHGs in the atmosphere. The measurements were conducted by a Picarro G2401 analyzer. Specific calibration routines were carried out using the primary standards of calibration from National Oceanic and Atmospheric Administration – Global Monitoring Laboratory (NOAA – GML), as well as secondary standards were used to evaluate possible drifts, and the stability of calibration factors. This coastal monitoring station, located 600 m from the Tyrrhenian Sea shore, allows to study atmospheric carbon dioxide (CO_2) ppm and methane (CH_4) ppb concentrations at the local and continental scales, in a region with peculiar Mediterranean climatic features. This work presents a preliminary characterization of CO_2 and CH_4 variability in the central Mediterranean basin. We show the hourly concentration data of GHGs over a 9-years period, from 2015 to 2023, that represent a relevant long-term dataset of these gases over Southern Italy. This work would be a gainful contribution towards a more accurate knowledge of greenhouse gases trends in the atmosphere in the central Mediterranean region.

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Forest ecosystem transpiration and carbon sequestration at the footprint level of an ICOS site

Holger Lange, Junbin Zhao, Morgane Merlin, Ryan Bright

NIBIO, Ås, Norway

Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Transpiration is an important water flux in forests closely tied with carbon dioxide (CO_2) sequestration through stomatal control at the tree level. While it is a key process underlying water and carbon fluxes, it remains challenging to measure transpiration at larger spatial scales. In the footprint of the ICOS class 2 tower at Hurdal in Norway (NO-Hur), we installed sap flow probes (Heat Field Deformation and Heat Ratio Method) on 13 Norway spruce trees, and automatic point or band dendrometers on 25 trees, measuring time series of transpiration and stem diameter fluctuations at 10 minutes resolution. We analyze the relationship between stem diameter changes and sap flow, and the dependence of this relationship on physical attributes of individual trees (height, diameter at breast height, age, sapwood length), meteorology and soil climate. Phase Synchronization Analysis reveals that there is a delayed response of diameter change to sap flow, and we thus construct a time-lagged empirical model representing flow patterns across diurnal and seasonal cycles. This model allows for predicting tree-level transpiration also for trees not equipped with sap flow devices. Using the ICOS forest inventory and Lidar data, we develop a dynamic model for the total transpiration within the footprint (average area 0.63 km^2) at high temporal resolution. Combining the tree level measurements with ecosystem level eddy covariance data, we also explore the coupling of carbon and water fluxes and how sap flow and dendrometer data contribute to explain ecosystem CO_2 sequestration.

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The Integrated Greenhouse gas Monitoring System (ITMS) for Germany: an update on recent progress

Christoph Gerbig[1], Andrea Kaiser-Weiss[2], Heinrich Bovensmann[3], Ralf Kiese[4], Clemens Scheer[4], Rachael Akinyede[1], Beatrice Ellerhoff[2], Maximilian Reuter[3], Hannes Imhof[4], Christian Plaß-Dülmer[5], Andreas Fix[6]

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

The Integrated Greenhouse Gas Monitoring System for Germany (ITMS) is a national initiative to establish an operational service for the provision of independent estimates of GHG fluxes for Germany. The main aim is to enhance transparency in reporting of emissions and natural fluxes, specifically with regards to emission reduction on the path to net zero. ITMS is a highly interdisciplinary project, bringing together diverse scientific communities involved in atmospheric observations, satellite observations, biosphere and agriculture research, inventory experts, and atmospheric transport and inverse modelling. ITMS utilizes observational datastreams from research infrastructures such as ICOS and IAGOS to constrain Germany's GHG fluxes into the atmosphere using inverse atmospheric transport modelling. ITMS also develops tailored remote sensing products e.g. from current and upcoming satellite missions. Detailed a priori emissions are generated consistent with UNFCCC reported emissions, while priors for natural fluxes are based on various process based as well as diagnostic models. Inverse modelling is deployed at mesoscale resolution, using the CarboScope-Regional (CSR) inversion system operated at the MPI- BGC as a back-bone and reference system, while developing ICON-ART based data assimilation for future operational services at the DWD. The presentation will give an overview of current status, and will indicate some research highlights achieved so far.

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European Obspack: compilation of all CO_2, CH_4 and N_2O measurements in Europe

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

The dense network of greenhouse gas observations enables us to characterize trends and seasonal anomalies on a regional scale. The ObspackEU dataset was initiated in 2022, covering at that time CO_2 and CH_4 observations. After its first update in September 2023, the dataset represented in total more than 1170 years of CO_2 data and more than 1026 years of CH_4 data, distributed among 65 stations, 38 of which are ICOS-labelled. Thus, ICOS-labelled data represent about 36.5% of the total dataset, with a proportion increasing up to 72.6% when considering only 2022 data. For the year 2024, a new update scheduled for July, will aggregate data up to the end of March 2024 enriched for the first time with N_2O time series. 28 stations are foreseen to provide data which should represent around 450 years of measurements in Europe. We will present updated growth rates for the three main greenhouse gases, as well as the striking seasonal anomalies observed in Europe in recent years. We will present how these seasonal anomalies observed at stations can be propagated using back-trajectories calculated at the ICOS carbon portal, in order to obtain a regional picture of concentration anomalies.

68

Influence of nutrient availability on water-use efficiency of European semi-natural ecosystems

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

The ecosystem CO_2 and H_2O fluxes are typically studied in the context of changing micrometeorological conditions, such as light, water availability, and temperature. However, CO_2 and H_2O budgets are further modulated by nutrient availability (NA) and air deposition (AD). The influence of changes in NA and AD is observable only over longer periods, thus when evaluating the time series of eddy covariance fluxes it is more practical to compare across different sites with contrasting levels of NA and AD. Water-use efficiency (WUE) is a useful indicator of ecosystem performance and fitness, and it allows us to evaluate changes in ecosystem functioning since it reflects the degree of stomatal regulation of carbon assimilation and water loss.

In this contribution, we will assess the effect of NA of nitrogen, phosphorus, and calcium ions on WUE. For this purpose, we take advantage of the existing leaf NA survey performed yearly on the sun-exposed part of the vegetation canopy within ICOS ecosystem stations. Though nutrient content in the soil is not available, leaf samples are expected to be a better measure as they should reflect both soil NA and nutrient accessibility to the plant. The wide selection of semi-natural ecosystems across Europe will allow us to evaluate the capability of the ICOS network to capture the impact of NA on WUE. Furthermore, we will evaluate how leaf NA relates to AD, especially in the case of nitrogen depositions. For this purpose, EMEP MSC-W modeled air deposition results will be used.

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Climate-induced changes in carbon flux dynamics of an alpine grassland: insights from transplantation experiment

Federica D’Alò[1], Olga Gavrichkova[1], Angela Augusti[1], Luigimaria Borruso[2], Leonardo Latilla[3], Michele Mattioni[1], Maurizio Sarti[1], Leonardo Montagnani[2]

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Alpine regions undergo faster warming rates than the global average as a result of climate change (CC). This makes them highly vulnerable to functional collapse. Alpine grasslands store significant amounts of carbon in the soil, but the impact of CC on their carbon storage and sequestration capacities is still uncertain. To assess the CC effects on CO_2 fluxes in alpine grasslands, soil monoliths were transplanted from 2500m to 1500m altitude in Val Veny, Courmayeur, Italy, simulating a 5°C temperature increase as projected for 2100 by the IPCC’s RCP8.5 scenario. Two transplantations were conducted: in 2022 (old plots) and in 2023 (new plots), allowing the study of carbon fluxes in different acclimation stages. Continuous chamber systems were installed to measure CO_2 efflux in transparent and opaque chambers with 15min time step in undisturbed control and transplanted in different years plots. During the measurement campaign, in August 2023, a 5-day heatwave occurred at both altitudes, providing insight into the extreme event impact. Our findings showed undisturbed plots acting as minor carbon sinks throughout the study period, while all transplanted monoliths acting as carbon sources, especially the new ones. Notably, increased temperature and dryness disrupted transplanted systems functioning, leading to a significant post-heatwave decline in carbon uptake. New plots experienced decreased leaf area and species composition changes due to selective mortality, additionally affecting carbon exchange. Our data highlight the important impact of CC, particularly heatwaves, on alpine grassland carbon balance, indicating that one year of acclimation is insufficient for sequestration function recovery.

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Comparison of gross primary productivity derived from satellite-based models with field-measured products: case studies of tropical peat swamp forests in Borneo, Southeast Asia.

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

The total quantity of carbon fixed by photosynthesis per unit time in an ecosystem is referred to as gross primary productivity (GPP), and it is an important activity in the Earth's carbon cycle. In near-equilibrium conditions, GPP is calculated as the sum of daily net carbon exchange and ecosystem respiration (GPP = NEE − R_e). In our study, we compared the GPP from satellite-based model estimates with the actual GPP calculated by the eddy covariance method available from the FLUXNET database. We found that the GPP models were able to capture the actual 8-day fluctuations of GPP in tropical peat swamp forests in Borneo (R^2 = 0.29–0.33) and model performances showed good estimates (RMSE = 0.70–2.02; MAPE = 5.64–15.33%). Cloud cover on MODIS satellite data is also a challenge in measuring remote sensing indices such as the land surface water index, which is very important as a proxy for W_{scalar} to estimate GPP-based models.

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Influence of open fire emissions to carbon dioxide (CO_2) observed at the Mt. Cimone station (Italy, 2165 m asl).

Paolo Cristofanelli[1], Pamela Trisolino[1], Calzolari Francescopiero[1], Busetto Maurizio[1], Claudia Roberta Calidonna[2], Amendola Stefano[3], Arduni Jgor[4], Cosimo Fratticioli[5,6], Rabia Ali Hundal[7], Michela Maione[4], Francesca Marcucci[3], Angela Marinoni[1], Laura Renzi[1], Fabrizio Roccato[1], Paolo Bonasoni[1], Davide Putero[8]

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

This work aimed at investigating on a multi-year framework (2015 – 2021) the contributions of open fire emissions to CO_2 observed at the ICOS atmospheric class-2 station Mt. Cimone (CMN, 2165 m a.s.l. - Italy). A methodology providing indications about the possible presence of wildfire plumes from different European source regions was based on the observed CO, active open fire by MODIS and air mass back-trajectories. An alternative detection method based on the use of a reanalysis dataset (CAMS) was also used.

The results suggested that CMN could be affected by open fire plumes for a fraction of time ranging from 1% to 10% (as a function of the adopted methodology setting). We found a potentially important contributions from Eastern Europe during October - April, while during May - September there was a prevalence from the Mediterranean sectors.

We detected a notable increase of CO_2 residuals with respect to periods not affected by fire perturbations during October - April (from +1.8 to +3.9 ppm, on average). We did not find evident impacts during the summer months, possibly due to a contribution by biospheric uptake during air mass transport to CMN (at least for a fraction of selected events).

We discussed the sensitivity of results as a function of the selection methodology settings, suggesting that the strictest set-up based on the detection of large CO excesses could trace “major” events. A medium level of agreement was found when comparing the our selection methodology with CAMS reanalysis (fraction of PM_{10} emitted by wildfires).

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Evaluating the Short-Term Influence of Restoration on Net Ecosystem CO2 Exchange (NEE) in an Irish Peatland

Md Shamsuzzaman[1], Shane Regan[2], Mark O'Connor[2], Ultan McCarthy[3], Imelda Casey[3], Mika Korkiakoski[4], Owen Naughton[1]

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

Peatlands serve as vital reservoirs for carbon storage, harboring over 50% of the Republic of Ireland's soil carbon. However, years of mismanagement, including practices like drainage and peat extraction, have transformed these areas into significant carbon emitters. Restoration initiatives are pivotal in Ireland's commitment to reducing greenhouse gas emissions by 30%, as outlined in the national Climate Action Plan and the Paris Agreement.

Initiated by the National Park and Wildlife Services (NPWS) in 2019, a restoration project commenced at the All Saints raised bog in County Offaly, a designated Special Area of Conservation. Employing an Eddy Covariance tower, we monitored the net ecosystem CO2 exchange (NEE) over a nearly three-year period before and after restoration. Preliminary findings show promising outcomes, notably the establishment of a crucial water reserve supporting the bog's ecosystem. However, despite ongoing restoration, significant carbon emissions persist.

NEE data illustrates fluctuating trends, with readings rising from 110.89 g C/m^2 in 2021 to 214.37 g C/m^2 in 2022, gradually declining as of summer 2023. Further analysis aims to elucidate emission patterns across time and seasons, discerning the key influencers, encompassing both biotic and abiotic factors. This holistic approach provides invaluable insights into restoration efficacy and enhances our comprehension of carbon dynamics within peatland ecosystems. Such insights are indispensable for shaping future conservation strategies and achieving Ireland's climate objectives.

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Nocturnal fluxes of CO_2 and CH_4 from Barcelona Metropolitan Area obtained with the Radon Tracer Method

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Urban areas represent the major contributor to the global greenhouse gas (GHG) emissions to the atmosphere. Quantifying their GHG emissions and constraining the associated uncertainties is a scientific challenge and a key factor for fighting the climate change.

Continuous atmospheric measurements of carbon dioxide, methane and of the tracer radon gas have been carried in the INTE-IDAEA station in Barcelona city since January 2022. The GHG measurements, together with ones from three more stations within Barcelona Metropolitan area, are part of the ICOS Cities project.

Both ^{222}Rn and GHG measurements were analysed and integrated with backtrajectories within the Radon Tracer Method (RTM) to obtain nocturnal fluxes of both CH_4 and CO_2 for 2022-2023 period. Fluxes estimated using RTM do not differ from those obtained from emission inventories such as EDGAR. Concentrations show a clear annual cycle but fluxes of both CO_2 and CH_4 remain quite constant along the year, in agreement with inventories.

This study was possible thanks to a collaboration between researchers from the Universitat Politecnica de Catalunya, the Universitat Autonoma de Barcelona and the Consejo Superior de Investigaciones Científicas.

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Using optical and radar inputs data in a machine learning model to predict net ecosystem exchange of cropland

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Agriculture is a major contributor to human-induced greenhouse gas emissions. At the same time, agricultural soils have been identified as having great potential to sequester carbon through the introduction of improved management practices, such as cover crops. In order to implement these practices at large scale, a better understanding of the CO2 exchange at the soil-atmosphere interface is required.

Different methods exist to quantify this flux. Direct methods such as flux tower measurements are accurate but limited in spatial coverage. Modelling approaches allow a broader spatial application but they are often crop specific and need to be calibrated for each crop type. Methods using machine learning approaches are emerging and offer important potential for predicting net ecosystem exchange across different crop types.

In this study we present a promising machine learning (ML) approach that is validated using ICOS network flux data. In addition to meteorological data, remote sensing information is used as input to the ML model. The contribution of optical and radar data is evaluated.

Training and validation are performed on ICOS data, and we also compare the flux predicted by the model with the flux estimated by an accurate remotely sensed crop model, SAFYE-CO2.

This study is part of our mission to provide operational tools to quantify the impact of agro-ecological practices on CO2 exchange and thus on soil organic carbon.

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At-sea intercomparison of a membrane-based pCO_2 sensor and a traditional showerhead equilibrator system

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Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

The partial pressure of carbon dioxide in seawater (pCO_2) is an essential ocean variable needed to calculate air-sea gas exchange and to identify marine carbon sinks and sources. Recent technological developments support autonomous pCO_2 measurements with reduced size and cost sensors. In July 2021, different instruments were tested in a laboratory setting during the ICOS OTC Intercomparison, where a key message following the experiment was the need for further field comparisons. Here we present the results from a field test of two generations of 4H-Jena HydroC CO2-FT membrane-based sensors alongside a General Oceanics instrument that uses a more traditional equilibrator. The inter-comparisons were done onboard a Ship-of-Opportunity regularly travelling between Europe and South America. The first stage of the experiment took place in 2021, when the difference between the two instruments was within ± 10 µatm for 52% of the comparison time. For the second stage of the experiment, several improvements were made, including an automated cleaning routine, installation of a new membrane sensor prototype with the ability to measure a reference gas, better sensor temperature measurements and an updated data processing technique. Following the changes, the performance during the 2023 comparison improved to within ± 10 µatm for 94% of the comparison time with the mean difference being 1.8 ± 5.5 µatm. This experiment revealed that, with the required adaptations, membrane-based sensors can adequately measure seawater pCO_2 at the Global Ocean Acidification Observing Network weather goal.

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Evaluating the consistency of methane emissions from regional inversions using different TROPOMI XCH4 satellite products

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

The analysis of observations of total column methane atmospheric mixing ratios (XCH4) from satellites with atmospheric transport inverse modeling should strongly increase the capabilities to monitor the methane emissions at regional scale.

The TROPOspheric Monitoring Instrument (TROPOMI) on-board the Sentinel-5 Precursor (S5P) satellite launched in 2017 provides XCH4 with global daily coverage and a relatively high (5.5×7 km^2) horizontal resolution. Widely used for the detection and inversion of XCH4 plumes associated to local super-emissions, TROPOMI-CH4 data is also exploited in regional and global flux inversions for the mapping of CH4 emissions.

Several products of XCH4 retrievals from the raw spectra measurements have been developed and they are routinely updated. The operational OFFL dataset is known to bear large biases. The SRON product relies on improved algorithms compared to OFFL, and on a correction for albedo-correlated bias. The WFMD product is based on the University of Bremen's WFM-DOAS algorithm. The BLENDED product is a corrected version of the SRON product. The corrected bias is estimated with a machine learning model, which was trained to predict the differences between TROPOMI and more mature GOSAT retrievals. Even if retrieval procedures have improved recently, previous intercomparison of the datasets revealed discrepencies at local and country scale.

We assimilate these four TROPOMI XCH4 products in atmospheric inversions of the regional emissions in Europe and South America in 2019 using the CHIMERE transport model, coupled to the inverse modeling platform Community Inversion Framework (CIF). Surface measurements are used as reference for validation. The presentation first focuses on the inversions for Europe at 0.5°×0.5° resolution. Secondly, we present results from the intercomparison of inversions for South America at 0.2°×0.2° resolution. We will perform Observing System Simulation Experiments (OSSE) to estimate the uncertainties of retrieved fluxes and interpret differences between inversions. We plan to inquire into the impact of differences between XCH4 products on inversion results and retrieved methane fluxes at the local (pixel), country and regional scale.

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Continuous CH_4 carbon isotope measurements in Italy: preliminary results from the Lampedusa observatory (Strait of Sicily) and general outline of the developing cross-country network

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Theme

1. Isotopes and other tracers for studies of methane sources and sinks

Abstract Text

Among greenhouse gases (GHG), methane (CH_4) is showing several degrees of uncertainty and unpredictability in its patterns: though a clear upward trend driven by anthropic activities has been reported and is now well acknowledged, the source apportionment of methane emissions and major shifts in sink processes cannot be fully explained. Although a decreasing trend in the carbon 13 isotope ratio of methane ($\delta^{13}C$-CH_4) might suggest an increased influence of biogenic sources to the total atmospheric budget in the past few years, the reasons behind this isotopic shift are still unknown. With climate change proceeding at a very fast pace, a detailed understanding of GHG budget is needed, and can be achieved by increasing the number of atmospheric stations that integrate carbon isotopes in their observations. The Italian branch of ICOS is now developing a cross-country network for this purpose. Here we present preliminary results from the Lampedusa observatory, located south of the Strait of Sicily and operated by the National Agency ENEA. A general outline of the developing network of atmospheric carbon isotope measurements in Italy is also presented: the Lampedusa observatory will be integrated into the network including Lamezia Terme (Calabria, Southern Italy) and Monte Cimone (Emilia-Romagna, Northern Italy), both operated by CNR-ISAC, as well as Potenza (Basilicata, Southern Italy), operated by CNR-IMAA. Each observatory has distinct environmental peculiarities and isotopic data gathered from the developing network are expected to contribute significantly to our knowledge of methane sources and sinks in the central Mediterranean Sea area.

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Estimation of Net Ecosystem Exchange (NEE) over Europe for 2018 using Community Inversion Framework (CIF) - STILT

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Atmospheric inversions have been widely used to understand and quantify the fluxes of greenhouse gases (GHGs) in the atmosphere, both in global and regional scales. The Community Inversion Framework (CIF) is an effort to bring multiple atmospheric inversion schemes under a comprehensive framework to estimate the fluxes of various GHGs and reactive species both at the global and regional scales (Berchet et al., 2021). In this study, we used the Lagrangian transport model STILT within CIF and performed CO_2 inversion over Europe for the year 2018 by using observations from 44 ICOS stations. Hourly Net Ecosystem Exchange (NEE) calculated with VPRM is optimized in the inversions while anthropogenic emissions from EDGAR and ocean fluxes from Fletcher et al., (2007) are prescribed. The surface sensitivities "footprints" were pre-calculated by STILT, driven by meteorological forecasting fields from ECMWF. The results from the CIF-STILT inversions were compared with corresponding estimates done by Munassar et al., (2023) wherein CO_2 inversions with a similar setup were carried out using the Jena Carboscope Regional (CSR) and LUMIA inversion systems. The similarities in the results as well as the potential causes for differences are assessed.

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Potential response of the Baltic Sea Carbon Cycle to Extreme Events

Anna Rutgersson, Erik Nilsson, John Prytherch

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

Marginal seas are a dynamic and still to large extent uncertain component of the global carbon cycle. As the biological activity in general is high, they represent a relatively large part of the global carbon cycle. While continental shelves represent 7 % of the oceanic surface area, they are estimated to contribute to approximately 15% of the open ocean sink. In general, coastal seas show a high variability of the CO2 system. This high variability, generated by the complex mechanisms driving the CO2 fluxes, complicates the accurate estimation of these mechanisms. This is particularly pronounced in the Baltic Sea, a semi-enclosed sea at high latitudes, with very variable atmospheric forcing and a strong seasonal cycle. A number of studies have evaluated whether the Baltic Sea is a sink or source of carbon changes with climate without a clear consensus, for this it is also important to understand how the Baltic Sea carbon cycle responds to extreme events. By using 15 years of data from the marine ICOS-site Östergarnsholm we evaluate the impact on surface concentration of carbon dioxide (used as an indicator of the carbon response) of warm/cold seasons and high/low wind seasons in addition to changes in the upwelling frequency.

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Radiocarbon Isotopic Disequilibrium Shows Little Incorporation of New Carbon in Mineral Soils of a Boreal Forest Ecosystem

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Boreal forests fix substantial amounts of atmospheric carbon (C). However, the timescales at which this C is cycled through the ecosystem are not yet well understood. To elucidate the temporal dynamics between photosynthesis, allocation and respiration, we assessed the radiocarbon (^{14}C) disequilibrium (*D*) between different C pools and the current atmosphere to understand the fate of C in a boreal forest ecosystem. Samples of vegetation, fungi, soil and atmospheric CO_2 were collected at the Integrated Carbon Observation System (ICOS) station Svartberget (SVB) in northern Sweden. Additionally, we analysed the $\Delta^{14}C$-CO_2 from incubated topsoil and forest floor soil respiration (FFSR) over a 24-hour cycle and calculated the $\Delta^{14}C$ signature of the total ecosystem respiration (*Re*) using a Miller-Tans plot. We show that vegetation pools presented a positive *D* enriched with bomb ^{14}C, suggesting a fast-cycling rate (in the order of months to years) for living biomass and intermediate (years to decades) for dead biomass. In contrast, mineral soils showed a negative *D,* indicating minimal incorporation of bomb ^{14}C. FFSR showed diurnal $\Delta^{14}C$ variability with an average value (mean = 8.5‰), suggesting predominance of autotrophic respiration of recently-fixed labile C. Calculations for $\Delta^{14}C$ in *Re* (median = 12.71‰) demonstrate the predominance of C fixed from days to decades. Although the boreal forest stores significant amounts of C, most of it is in the soil organic layer and the vegetation, where it is cycled relatively fast. Only minimal amounts of recent C are incorporated into the mineral soil over long timescales.

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Integrating Ameriflux Data in the CarbonSpace Platform

Andrey Dara, Robert Granat, Rafael Fabbrini, Nathan Streisky, Geza Toth

CarbonSpace Ltd, Dublin, Ireland

Theme

14. Leveraging Direct Flux Measurements Beyond Academia for Real-World Applications

Abstract Text

CarbonSpace, an innovative online cloud-based platform, revolutionizes the estimation of CO2 fluxes by harnessing optical satellite imagery and advanced meteorological reanalysis data through machine learning regression. Our unique process combines bottom-of-atmosphere surface reflectance and land surface temperature from Landsat bands with select AgERA 5 variables, creating robust predictor variables. Net Ecosystem Exchange (NEE) from the Fluxnet2015 dataset serves as a reference of our estimates.

Our approach has contributed to reliable assessments in Nature-Based Solutions (NBS) projects and agricultural plantations. Leveraging Landsat imagery, CarbonSpace achieves a spatial resolution of up to 30 meters, with flux estimates generated monthly. Fluxnet's network, featuring 212 eddy-covariance towers spanning diverse biomes and land covers, underpins our data's reliability.

Through station-stratified cross-validation, we demonstrate our model's capability to accurately estimate carbon fluxes across different regions with similar land cover types, even in the absence of local flux towers. However, the density and distribution of these towers in certain biomes influence the precision of remote sensing-based estimations.

Our platform allows for the integration of new datasets, enhancing our estimation capabilities. In this presentation, we demonstrate improvements achieved by incorporating Ameriflux data into our reference framework and make the case for expansion of flux networks to generate robust, global estimates of GHG fluxes.

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Artificial Neural Networks to estimate XCO_2 from OCO-2 space-borne observations

Cédric Bacour, François-Marie Bréon, Frédéric Chevallier

LSCE, Gif-sur-Yvette, France

Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

We have developed an Artificial Neural Networks (ANN)-based processing chain for the estimate of XCO_2 from OCO-2 observations over land surfaces. The ANN training combines real OCO-2 L1b observations with XCO_2 estimates from the CAMS (Copernicus Atmosphere Monitoring Service) modeling. The retrieval accuracy and precision are comparable to or better than the official retrieval algorithm (ACOS), which relies on full-physics radiative transfer model inversion and subsequent empirical bias correction, for soundings within the ANN training period. In addition, the ANN is also capable of representing small scale features (plumes) that are generated by strong localized emissions and which are not embedded in the CAMS database used for the training.

However, we observed degraded performance when the ANN is applied to observations acquired over a time period not included in the training database (as for instance one missing year in the middle of the training period). For near-real time processing, where observations inherently extend beyond the training period, the challenge of extrapolation for ANN becomes even more critical. We have observed that for soundings acquired one year after the end of the training period, the retrieval bias is on the order of the atmospheric CO_2 concentration growth rate (of 2.5 ppm).

We will present the ANN retrieval approach and assess the performance of the ANN-based XCO_2 estimates in comparison to the ACOS product. We will outline the current limitations of the approach and discuss ongoing research efforts aimed at mitigating the observed generalisation issue.

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Variability of surface seawater fCO_2 in the coastal region off Brazil sampled by the France-Brazil ICOS Station

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Theme

7. Carbon Cycling along the Land Ocean Aquatic Continuum

Abstract Text

The fugacity of CO_2 (fCO_2) has been measured underway in the ocean and in the atmosphere on board a merchant ship sailing from Europe to South America since 2008. This ship of opportunity line is part of the ICOS network. During its journey, the ship samples a wide range of oceanic provinces. This line has a particular interest as it samples the South Atlantic, a poorly documented region. Here we focus on the region close to the coast of Brazil from 12°S to 4°S. We have used 78 voyages made from 2008 to 2023 to examine the fCO_2 variability as a function of latitude and longitude. Two distinct regions are identified north and south of 8°S. The water mass from 12°S to 8°S comes from the southern branch of the South Equatorial Current (SEC), whereas further north (8°S-4°S), the central branch of the SEC explains the higher fCO_2 values and the lower surface salinity. Both regions are a source of CO_2 to the atmosphere, with stronger CO_2 outgassing occurring north of 8°S. The voyages from 12°S to 8°S show a cross-shore variability with a significant increase of fCO_2 towards the open ocean, and a significant decrease of surface salinity (*p-value*<0.05). The offshore decrease of salinity is also evidenced on the satellite salinity from SMOS. The ocean surface circulation is likely responsible for the different patterns observed in this region.

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ENVIRONMENTAL MONITORING OF COAL MINING AREA: LESSONS LEARNED FROM GROUND-BASED CH_4 MEASUREMENTS

Yaroslav Bezyk[1,2], Jarosław Necki[1], Miroslaw Zimnoch[1], Paweł Jagoda[1], Jakub Bartyzel[1], Carina van der Veen[3], Thomas Röckmann[3]

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Theme

1. Isotopes and other tracers for studies of methane sources and sinks

Abstract Text

The Upper Silesian Coal Basin in Poland is known for persistent enhancement of methane visible from space. Therefore, creating a reliable CH_4 inventory for underground coal mines requires accurate in-situ measurements of associated emissions, with particular attention to stable isotope signatures of the source. The analysis is based on three intensive measurement campaigns, initiated in June and October 2022, and continued in June 2023, along with monthly mobile monitoring of coal mining methane trends from active and abandoned coal mines spanning from February 2023 to January 2024.

The temporal and spatial variability of CH_4 levels in USCB, obtained from ground-based surveys of individual ventilation shafts, is combined with the Gaussian plume model and the EPA OTM-33A method. The mobile platform includes the LGR MGGA918, Licor 7810, Picarro G2201-i isotope analyzer. The results reveal an enhancement of CH_4 (from 2.1 to 6.4 ppm) in the plumes detected several kilometres downwind of active ventilation shafts in most study cases. The estimated methane emission rate, which varies depending on the examined shaft, falls within range between 103±32 kg/h and 1490±634 kg/h.

In comparison, the data collected during the surveys near abandoned coal mines under different weather conditions (cyclonic and anticyclonic circulations) did not indicate a significant methane plume from the non-active mining area. The isotope signatures (–49.1±1.9 ‰ for $\delta^{13}C$; –182.2±14.7 ‰ for $\delta^{2}H$) of CH_4 in the near-source plumes, calculated using the Keeling plot approach, suggest a primarily thermogenic origin of the coalbed gas in the USCB region.

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Evaluation of the nitrogen oxide emission inventory with TROPOMI observations

Chian-Yi Liu, Yi-Chun Chen, Charles Chou

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

To compensate for the emissions missed or underestimated in the national bottom-up emission inventories, we apply the high spatial resolution satellite data from TROPOspheric Monitoring Instrument (TROPOMI) to estimate the top-down nitrogen oxide (NOx) emissions in regional scales. The NOx chemical lifetime is derived based on ground-based measurements of ozone photolysis rate, ultra-violet (UV) index, and temperature. For five designated regions of western Taiwan, the derived lifetime is about 1–2 h in summer and 2–4 h in winter. The retrieved 2021 annual emissions for regions near two major pollution sources, Taichung thermal power plant and Mailiao Industrial Zone, are comparable with the emission from the Continuous Emission Monitoring System (CEMS), with a difference of 6% and -12%, respectively. After validating the data and methods, the NOx emissions for five regions of western Taiwan are derived and applied to evaluate the bottom-up inventories. For northern and southern Taiwan, the top-down emissions agree well with emission inventories. The top-down emissions are 12%, 23%, and 16% higher than emission inventories for north-central, central, and southcentral Taiwan, respectively. This indicates that the bottom-up inventories are underestimated from northcentral to south-central Taiwan, which may be associated with the uncertainties from traffic sources. Given the various complex pollution sources, deriving NOx emissions from space allows us to acquire a better understanding of emissions on urban scales and improve the bottom-up emission inventories.

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Analysis of urban CO_2 and heat fluxes and evaluation of the SUEWS model using eddy covariance observations from two towers in Heraklion, Greece.

Konstantinos Politakos[1], Emmanouil Panagiotakis[1], Dimitris Tsirantonakis[1,2], Stavros Stagakis[1,3], Nektarios Spyridakis[1], Christian Feigenwinter[3], Matthias Roth[4], Nektarios Chrysoulakis[1]

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Urbanization drives global CO_2 levels higher, mainly due to human activities like fossil fuel combustion for heating, industry, and transportation. Emissions vary spatially based on factors like population density, land use or urban structure, underscoring the need to measure and understand local emissions to manage city-wide carbon budgets. The present study analyzes CO_2, sensible and latent heat fluxes from two ICOS Associated eddy covariance flux towers in the city of Heraklion, Greece. Despite their proximity, only 1.5 km apart from each other, HECKOR and HECMAS represent distinct land use types: HECKOR is in the commercial city center, while HECMAS is in a residential area. Seasonal and diurnal CO_2 flux patterns are therefore significantly different across the sites. HECKOR's fluxes align with commercial and working hours year-round, while HECMAS primarily captures CO_2 emissions from residential heating during winter with only small fluxes during other times of the year. Furthermore, there is extreme directionality in CO_2 fluxes measured in HECKOR, and thus the estimated diurnal patterns are affected by the seasonality of wind direction patterns. Dynamic flux footprints from both towers are analyzed to link observed CO_2 fluxes to specific land use and land cover features. Additionally, we utilize the latest SUEWS CO_2 modeling module, integrating TomTom traffic data and flux footprints to assess surface emissions alongside in-situ flux tower data. We also observe higher sensible heat fluxes in HECKOR, most probably due to higher building density and lower vegetation cover in the Heraklion central commercial district.

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European methane flux estimates for 2022 based on the Radon Tracer Method, regional atmospheric inversions and inventories

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

The Integrated Carbon Observation System (ICOS) is a European research infrastructure, which provides compatible, harmonized and high-precision scientific data on the carbon cycle and greenhouse gases (GHGs). Its atmospheric component consists of 39 stations predominantly located in Europe. Within ICOS atmosphere stations, CH_4 measurements are mandatory, while ^{222}Rn measurements are recommended.

Methane is the second most important anthropogenic GHG after CO_2 and is emitted by multiple sources whose locations and magnitude still remain incomplete.

^{222}Rn is not a GHG but it is emitted naturally in a relatively diffuse way from rocks and soils. With a lifetime of a few days, it serves as a proxy for surface-atmosphere interaction and, consequently, as a tracer for atmospheric transport and mixing studies. The Radon Tracer Method (RTM) combines radon and GHG observations to derive estimates of GHG fluxes at local to regional scale.

In this work, we compare the methane flux estimates for Europe in 2022 obtained from three different methods. 1) the RTM applied to methane and radon data from 16 ICOS stations combined with radon exhalation maps and simulation of the station atmospheric footprints 2) atmospheric inversions based on the Community Inversion Framework coupled to the regional-transport model CHIMERE, assimilating either the methane mixing ratio from the same ICOS stations, or total columns CH_4 observation from the TROPOMI satellite instrument 3) an extraction of the anthropogenic emissions from inventories such as EDGAR and TNO.

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A new IFS 125HR FTIR instrument for the measurement of trace gases over the Po Valley

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CNR-ISAC, Bologna, Italy

Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

In the frame of the ITalian INtegrated Environmental Research Infrastructures System (ITINERIS), the Italian research institute CNR-ISAC will acquire a new Bruker IFS 125HR FTIR spectrometer in the next year.

The IFS 125HR instrument will be installed in Bologna and will be equipped with all the accessories necessary to make its spectra compliant to its dedicated global measurement networks: the Network for the Detection of Atmospheric Composition Change (NDACC) and the Total Carbon Column Observing Network (TCCON).

Its measurements will be used to retrieve information on several trace gases such as: O_3, HNO_3, HCl, HF, CO, N_2O, CH_4, HCN, C_2H_6, $ClONO_2$, CO_2, H_2O, O_2 and HDO. In particular, the high spectral resolution of its measurements will allow to retrieve information on different atmospheric layers for most of the mentioned species. This information, together with the one obtained with the operative instruments already present at the institute, are useful for the monitoring of air quality in the Po Valley. Moreover, their compliances to the mentioned global networks will make these measurements particularly suitable also for the validation of satellite data.

Here, we present the potentials of the IFS 125HR FTIR instrument within the ITINERIS project.

We thank the support of the Italian Ministry for Universities and Research through IR0000032 – ITINERIS, Italian Integrated Environmental Research Infrastructures System (D.D. n. 130/2022 – CUP B53C22002150006) Funded by EU – Next Generation EU PNRR – Mission 4 “Education and Research” – Component 2: “From research to business” – Investment 3.1.

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Trees functioning under excess or lack of water

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

In the era of changing climate and the increasing intensity of extreme phenomena on a global scale, it has become particularly important to understand the response of widely distributed plant species
to changing living conditions and various types of stresses. Scots pine and silver birch are adapted to and widespread in both boreal and temperate regions. In the boreal and temperate regions, extreme phenomena are observed that have not occurred with such frequency and intensity in the past, especially droughts, floods and wildfires. In the presented work, we focused on the aspects of lack and excess of water, which lead to similar disturbances in the functioning of trees. Lack of oxygen for the tree roots means problems with energy production and disturbs sap flow and, consequently, transpiration, as does the lack of water.Scots pine and silver birch have been found to grow in drought-prone conditions (e.g., central Poland, central Germany), as well as in wet and flooded zones (e.g, Finnish wetlands). The aim of the study was to assess the transpiration, productivity and resource use capacity of Scots pine and silver birch in various environmental conditions. Trees growing on the bog-forest transect (in Southern Finnland) and trees in areas with annual rainfall falling below 400 mm (in central Poland) were used. We also present results concerning tree transpiration and productivity obtained from a Scots pine forest after a low severity wildfire (in central Sweden).

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Understanding Variability in Methane Flux Measurements: Results from an Expert Survey on Chamber Flux Methods

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Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

Advances in laser spectroscopy have improved the analysis of key trace gases like CH_4 and N_2O, opening new possibilities through both portability and with reduced measurement times using high-frequency (>1 Hz) data. However, high-frequency and high-accuracy CH_4 concentration measurements also pose challenges in the interpretation of CH_4 fluxes due to non-linear behavior from earlier protocols using longer measurement times with fewer samples. Here, we used a community survey to investigate the approaches for chamber fluxes used by different researchers. We received nearly 40 responses indicating that ~75% of respondents have adopted high-frequency, multi-gas analyzers with most measurement times between 2-5 minutes. We presented a standardized set of CH_4 concentrations from observed flux measurements and asked about their approach to quality control and flux calculations. We

found strong agreement among the experts when CH_4 fluxes exhibited linear behavior but two main approaches for non-linear fluxes. Many survey respondents discarded the initial part of the measurements due to initial disturbance related to chamber placement, while roughly the same number selected the initial part and discarded the later part of the measurements due to chamber saturation effects. Experts also strongly disagreed on the inclusion of fluxes around zero. Our study shows the need to understand drivers of the patterns visible from high-resolution analyzers and standardized procedure and guidelines for future chamber CH_4 flux measurements. This is highly important to reliably quantify methane fluxes all over the world and, especially in Arctic regions where we expect the greatest changes in the near future.

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Greenhouse gases emission and absorption in an extensive young walnut orchard (*Juglans regia L.*) in Italy

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

The role of agriculture in carbon (C) balance is still contrasting, since this sector can act as both a contributor to greenhouse gas emissions and a potential sink for carbon. In this perspective, field research activities aimed at measuring fluxes from agricultural systems should be implemented, particulralyover long-term agroecosystem such as orchards, where C can be stocked in woody compartments and soil for long time.

In this context, the first year of an experimental campaign over a 170-hectare wide plot of young (three-years) walnut trees (Juglans regia L.) is currently running in Bondeno (Emilia Romagna, Italy), to measure the GHG fluxes from this system.

The C-fluxes (Net ecosystem exchange, NEE) are measured using eddy covariance, while N2O emission are measured using real-time portable N2O trace gas analyzer (LI-7820 N2O /H2O, Li-Cor) connected with an automated soil chamber (LI-8200-01S Smart Chamber, Li-Cor). While C-fluxes are collected at high-frequency (30-min), N2O fluxes were measured along the growing season at monthly intervals and intensively after each mineral fertilization event. The total yearly GHG balance of the wall tree system is then expressed as CO2eq.

Preliminary results indicate that extreme and mean weather conditions coupled with agricultural practices (i.e, fertilization, tillage, pruning, etc.) may affect from daily to monthly C-N fluxes, strongly influencing the overall yearly GHG balance of the system.

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Carbon and water relations over three growing seasons in an African arid Savanna and grassy shrubland.

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Anthropogenic climate change and increasing atmospheric carbon dioxide could alter ecosystem and biogeochemical processes in African drylands, potentially affecting land-atmosphere feedbacks. We used a paired-site Eddy Covariance-based approach to compare carbon and water exchange in Savanna and Nama-Karoo biomes, revealing differences in phase and magnitude in carbon fluxes across multiple scales. A Total of -160 g C m^{-2}, was recorded at the Nama Karoo Site, versus a total of -567 g C m^{-2} over a period of 33 months, with mean annual NEE of -189g C m^{-2} y^{-1} and -53 g C m^{-2} y^{-1} for the Savanna and Nama Karoo sites, respectively. More carbon uptake was observed during periods of intermediate soil moisture at both sites, with soil moisture also observed to modulate the relationship between nighttime NEE and soil temperature. The rainfall required to trigger ecosystems (and initiate the start of the growing season) into carbon sinks varied across periods, with the Savanna site requiring between 131 mm and 172 mm, and the Nama-Karoo site requiring between 98 mm and 165 mm. A fire event in the second period nearly halved carbon uptake compared to the first period at the Savanna site, also delaying the start of the growing season even with higher rainfall received. The Nama-Karoo site had higher ecosystem water use efficiency (eWUE), but more variability in eWUE was observed at the Savanna site. Both vegetation types were consistent net carbon sinks over three growing seasons, with contrasts in functioning observed under similar climatic conditions.

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Urban and tropical EM27/SUN network for satellite validations, observations and verification of greenhouse gas emissions

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

The EM27/SUN instrument is a FTIR spectrometer allowing to retrieve total atmospheric column abundance of CO2, CH4, CO and H2O. LSCE is currently involved in two projects in which the EM27/SUN instruments are deployed in different environments for different purposes.

The OBS4CLIM project aims at deploying five EM27 by 2023 at observatories located in tropical (Bolivia, French Guiana, Morocco, Ivory Coast) and background regions (Amsterdam Island, Indian Ocean) for long-term observations and satellite validation purposes.

The ICOS-Cities project aims at evaluating different observational approaches to determine CO2 emissions from large cities, such as Paris. A chosen strategy consists in evaluating the Paris carbon budget by coupling total column measurement to inverse modeling. For that purpose, two EM27s are deployed in a north to south transect of Paris, in addition to the Paris TCCON site.

The rapid growth of this EM27/SUN network requires developing tools to ensure data quality and availability. Therefore, LSCE has developed:

- An automatic data treatment chain based on PROFFAST (developed and maintained at KIT). Two models are used as a priori profiles (GGG2020, and CAMS) allowing to retrieve daily data in near real-time (NUBICOS project).
- Automatic enclosure systems to protect the instrument from a rough environment. This system allows increasing drastically the daily observations and data availability.

We will present in detail the two major developments done at LSCE and necessary to obtain a robust network providing semi-continuous observations in near real time. Results from the OBS4CLIM and ICOS-Cities projects will also be detailed.

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VERBE - Towards a greenhouse gas emission monitoring and Verification system for Belgium

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

Like most countries, Belgium's national greenhouse gas inventory report to the United Nations Framework Convention on Climate Change is based on a bottom-up approach which combines statistical data about economic activities with activity-specific emission factors to calculate the total emissions. It has been shown that it is possible to improve the understanding of the national reporting by adding complementary information obtained using a top-down approach, combining atmospheric greenhouse gas observations with an inverse modelling framework.

VERBE (https://verbe.aeronomie.be) aims to develop such a system tailored for Belgium, and will combine satellite and ground-based infrared remote-sensing and ICOS in-situ observations with inverse modelling. Such in-situ and FTIR observations will be established in Belgium. The universities of Antwerp and Liège share their ecosystem (vegetation and soil) exchange modelling experience to provide biogenic fluxes, that will be combined with anthropogenic emission inventories to provide a-priori emissions. Those will be used with atmospheric transport and inversion models running at BIRA-IASB to provide a-posteriori emissions.

The VERBE project (01/09/2022 - 01/12/2026) supports the FED-tWIN research BE-MVS (A BElgian greenhouse gas emissions Monitoring and Verification System), and collaborates with colleagues developing similar systems in Germany and the Netherlands. The approaches of the UK and Switzerland, which have published top-down emission estimates for hydrofluorocarbons, CH_4, N_2O and CO_2 (UK) in the annexes of their latest reports, are also studied.

This poster gives an overview of the objectives of VERBE, and shows preliminary results of an FTIR measurement campaign around the city and port of Antwerp in April 2024.

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Inverse modelling of regional methane emissions from multiple sources using high frequency methane isotope observations

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Theme

1. Isotopes and other tracers for studies of methane sources and sinks

Abstract Text

Top-down inverse models can be used to estimate regional methane emissions, by combining high frequency methane concentration observations with output from an atmospheric transport model. These methods traditionally produce a monthly or annual estimate of total regional methane emission from all sources. However recent developments in this field, including those presented here, use observations of methane isotopes within the inverse model to directly estimate methane emissions from different sources.

Here, we present results from a Bayesian inverse modelling system that incorporates new high-frequency observations of both $\delta^{13}C(CH_4)$ and $\delta^{2}H(CH_4)$ from the Heathfield tall tower observation site in the south-east UK to estimate emissions from two broad source sectors. Methane isotope ratios used to characterise emissions sources can be uncertain and vary spatially and temporally. So this inversion method also optimises these isotope ratios simultaneously with emissions, whilst considering the uncertainty in all these variables.

We demonstrate the potential for this method to be used with an expanded network of methane isotope instruments across the UK. We then present fossil fuel and agricultural and waste emissions estimates for southern England from the inverse model with currently available high frequency isotope observations. We find that using both methane isotope and ethane observations together in the model provides a greater constraint on emissions from the fossil fuel sector and reduces overall uncertainty in the sector-level methane flux estimates.

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Working with C stock of soils in partly vegetated boreal/arctic environment and relation to landscape parameters.

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Theme

13. In situ data for climate and other environmental services and policy support

Abstract Text

One way to estimate GHG fluxes on terrestrial ecosystems is to record stock changes either as difference in stocks over a period of several years, or through chrono sequential rows shifting time with place, when dealing with fixed management regimes of different age. The chrono sequential approach requires series of sites under the same management that have started on land that in principle was identical regarding C stock. In cases where these conditions are not met, direct flux measurements or stock comparation are two remaining alternatives. Confronted with the task of evaluating carbon budget of extended grazing land with free roaming sheep grazing and basically no background information on carbon stock it was decided to start building a baseline for the stock evaluation. Extensive soil sampling scheme was set up and over ten years period (2007-2017) around 2000 locations were visited (Gudmundsson et al. 2021). At each location information on vegetation total cover and separated to functional categories, erosion marks, soil depth and land cover category was recorded, and soil and aboveground biomass sampled. Data analyses are still pending. As all locations are georeferenced our data can be directly connected to available or obtainable geographic attributes potentially aiding in explaining the pattern observed. We hereby offer for cooperation, sharing and analyses of the data in IGLUD database.

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A world of hexagons on graphics processing units: new numerical paradigms for atmospheric inversion

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

The coming exascale era of supercomputing offers a major opportunity to significantly increase the spatial resolution of global atmospheric inversion and thereby significantly improve current scientific capabilities for estimating greenhouse gas budgets at regional scale everywhere. However, the architecture of the new machines is primarily driven by Artificial Intelligence applications, rather than by scientific computing in the broad sense, and massively uses accelerated hardware such as GPU. Atmospheric inversion software must adapt to benefit from it. Here we present the design of the new CAMS CO2 inversion system which achieves a global resolution of 90 km (64,002 cells per vertical layer) on GPU-accelerated supercomputers while preserving the quarterly production rate for the Copernicus service: the code was ported to NVIDIA GPU devices and large-scale advection was rewritten to work on a Goldberg-polyhedron mesh, which exhibits no polar singularities unlike usual latitude-longitude meshes. The new code is faster, more compact, and more linear, and it runs efficiently on GPU at the desired resolution. When run at comparable resolution at the Equator, its simulations are very similar to the previous version, but they are still limited by the large volume of input meteorological data. We discuss its scalability from 180 km resolution to 90 km resolution, and the prospect of 22 km resolution, close to the native resolution of the underlying ERA5 reanalysis. Hardware and software environments are evolving rapidly and we also discuss future challenges for the code, including its portability given its current dependence on a specific vendor.

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Spatial modelling of biogenic CO_2 and heat fluxes in the city of Zürich

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Cities are taking actions to mitigate their climate impact. Reducing carbon dioxide (CO_2) emissions is crucial, but cities also need information about carbon sequestration. Green urban areas can be planned to maximize sinks and stocks of carbon, and in addition, they are crucial in reducing heat and enhancing cooling.

In this research, the city of Zürich, Switzerland, was modelled with the Surface Urban Energy and Water balance Scheme (SUEWS). This urban land surface model can simulate energy, water and CO_2 exchanges. Furthermore, it produces temperature profiles in the roughness sublayer (RSL). To simulate integrated cycles, meteorological forcing data and information about urban surface cover, such as land surface types and their parameters, is needed. A spatial model run of the city using 250x250 m^2 grids was done for the years 2022-2023, the first one being a spin-up. ICON-ART was used to produce meteorological forcing. The modeled air temperature was compared against the ICOS Cities rooftop sensor network, and modeled CO_2, latent and sensible heat fluxes against eddy covariance (EC) measurements conducted at the 111 meter tall Hardau II tower.

Results show that SUEWS captures the temperature variations in different areas around the city. The EC fluxes are also well-simulated. The spatial biogenic CO_2 maps give a sensible distribution of fluxes, meaning for example that the forests surrounding Zürich city center are the strongest sinks, but photosynthetic uptake also takes place in the more built-up areas. Later, canopy coverage will be linked with the modelled CO_2 exchange and heat.

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Eddy covariance measurements of Carbonyl sulfide (COS) to partition the urban carbon flux

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Cities are global hot spots of anthropogenic CO_2 emissions, contributing over 70% of the global emissions. The heterogeneous urban ecosystems generate net CO_2 fluxes (NEE) consist of many different anthropogenic and biogenic components, which cannot be distinguished from one another measuring only CO_2 with eddy covariance technique. Carbonyl sulfide (COS) is a trace gas taken up through the same pathway as CO_2 but not emitted back to the atmosphere. Hence, it can be used as a proxy for gross primary production (GPP).

The aim of this work is to examine the suitability of COS flux measurements to partition GPP and other components from urban NEE. For this, intensive measurement campaigns were conducted at ICOS Associated Ecosystem Station FI-Kmp in Helsinki between summer 2023 and spring 2024, and in Zürich over winter 2022–2023.

During the growing period, significant COS uptake associated with photosynthesis was observed in wind directions with high fraction of vegetated surfaces. In summer, in a highly vegetated urban area (Helsinki), we were able to successfully estimate GPP using COS flux and partition it from NEE. In wintertime, however, we saw an influence of anthropogenic emissions on COS fluxes, which complicates GPP estimates and sheds light on the details of global budget of COS, which has not been closed to the date. We show how COS based GPP estimates can be made in urban regions, but limitations on scale and accuracy need to be considered based on the flux source area.

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Celebrating the Surface Ocean CO_2 Atlas (SOCAT), a community-led synthesis, with WMO G3W on the horizon

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

The community-led Surface Ocean CO2 Atlas (SOCAT, www.info.socat) is a publicly available, annually updated synthesis of *in situ* surface ocean CO2 measurements with quality control for the global ocean. It is widely used for quantification of ocean CO2 uptake and ocean acidification and for evaluation of earth system models and biogeochemical sensors. However, SOCAT lost its European data management hub in 2022. In response the 'Case for SOCAT as an integral part of the value chain advising

UNFCCC on ocean CO2 uptake' was published in 2023. This was followed by the 'Declaration on operationalising the Surface Ocean Carbon Value Chain' in 2024. Delivery of routine global gridded products of air-sea CO2 flux is an ambition of the World Meteorological Organization's (WMO) Global Greenhouse Gas Watch (G3W) in its draft implementation plan for 2024-2027. To this purpose the G3W highlights the need to formalize and enhance SOCAT, notably by developing its infrastructure, by furthering interoperability with other ocean carbon products, by modernizing its computing infrastructure and by coordination with the MEMENTO (MarinE MethanE and NiTrous Oxide) data base for oceanic CH4 and N2O. Addressing chronic funding shortfalls and enhancing SOCAT to meet the G3W's ambition will require countries around the world to invest in SOCAT. Here we will celebrate SOCAT, highlight the challenges it is facing and present a vision of SOCAT within G3W.

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Continuous high-frequency CO_2, CH_4 and N_2O fluxes year-round from the boreal Siikaneva Bog, Finland

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

We measured CO_2, CH_4 and N_2O fluxes continuously year-round in high-frequency from the Siikaneva (FI) boreal peatland using an automated chamber system in the FluxWIN project, with sites ranging from a wet bog to a boreal forest on mineral soil. The wet bog was a small net sink of CO_2 in 2022. For CH_4 in particular, our data indicate that the wet bog is emitting up to 30 % of its annual budget during the shoulder seasons and winter, highlighting the important role of the non-growing season for budgets. Additional vegetation removal experiments were used to parse CH_4 emissions pathways, production, and oxidation throughout the year. These showed the importance of oxidation in the system and the interactions between temperature, water table, and vegetation. Parts of the peatland around the FluxWIN automated chamber system and the vegetation removal experimental site were classified for their vegetation categories via drone imagery. Together, these results can be used to improve the representation of CH4 fluxes and C cycling throughout the year.

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Anthropogenic CO_2, air-sea CO_2 fluxes and acidification in the Southern Ocean: results from a time-series analysis at station OISO-KERFIX (51°S-68°E)

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

We evaluated the temporal variation of air-sea CO_2 fluxes and pH in the Southern Indian Ocean based on both in-situ data collected since 1985 at a fixed station and reconstructions from a neural network model. During austral winter, the fugacity of CO_2 (fCO_2) in surface waters increased at a rate close or slightly lower than in the atmosphere over 1985-2020, whereas we observed contrasting trends in summer depending on the decade and related to changes in phytoplankton biomass. As a result, the regional air-sea CO_2 flux evolved from an annual source to the atmosphere in 1985 (0.8 $molC.m^{-2}.yr^{-1}$) to a sink in 2020 (-0.5 $molC.m^{-2}.yr^{-1}$). The annual pH trend in surface waters over 1985-2020 was -0.0165 ±0.0040.$decade^{-1}$ and was mainly controlled by the accumulation of anthropogenic CO_2 estimated from subsurface data at +0.53 ±0.01 $\mu mol.kg^{-1}.yr^{-1}$ with a detectable increase in the trend in recent years. However, the summer pH trends were also impacted by natural processes that reduced the acidification rate over the last decade. A projection of future total carbon concentrations for a high emission scenario (SSP5-8.5) indicates that the surface pH in 2100 could decrease to 7.32 during winter, 0.86 lower than the pre-industrial pH and 0.71 lower than the pH observed in 2020. For this scenario, the aragonite under-saturation in surface waters would be reached as soon as 2050 and 20 years later for the stabilization scenario SSP2-4.5, with potential impacts on phytoplankton species and higher trophic levels in the rich ecosystems of the Kerguelen Island area.

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Combining NDVI data and flux measurements to estimate CO2 GPP rate and annual photosynthesis.

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

By combining chamber CO_2 flux measurements and remote NDVI data, we were able to establish regression model for predicting site specific photosynthesis with reasonable accuracy applying photosynthetic active radiation (PAR) as main driving variable and NDVI as proxy for seasonal index on vegetation CO_2 uptake at available PAR. The NDVI remote sensed available values for individual site was utilised to establish site specific NDVI values for each Julian day (JD). The site specific NDVI values were connected to measured CO_2 uptake flux (photosynthesis (Pho)), arrived at by chamber measurements of net ecosystem exchange (NEE) and ecosystem respiration (R_{eco}). PAR was measured simultaneously with flux measurements. Fitting (eq1) to our Pho data, PAR and NVDI at same JD, returned R^2 of 0.83

Eq 1. Function of PAR and NDVI fitted to measured Pho

Pho=(a+ln(PAR))* e^((-0,5*   (((NDVI-x_0))/b)   ^2))

Arguing that photosynthesis of an area depends mostly on available energy (PAR) and the photosynthetic structures available to utilize the incoming energy, and the available structure represented by NDVI or LAI (leaf area index). Pho response to changes in PAR, keeping other parameters constant including available biomass, generally shows strong linear correlation to ln(PAR). Inclusion of a variable representing available structure logically would be a simple multiplication factor (Two structures do double as much as one). Testing that linear option returned by far weaker R^2 (~ 0.5-0.65) than above Gaussian relationship and indicating some other amplifying factors to photosynthesis than NDVI.

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BVOCs fluxes characterization from a Sorghum plantation in a Mediterranean ICOS site: exploring phenology, stresses, source and sink ripartition of the net ecosystem exchange

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Theme

2. Exchange of reactive gases and aerosols between the land surface and the atmosphere in natural and managed ecosystems

Abstract Text

Climate change will affect the growing season and increase the occurrence of extreme stressful events, altering crop phenological phases and biogenic volatile organic compound (BVOC) emissions, especially in the Mediterranean region.
In turn, VOCs significantly affect atmospheric processes and climate. Understanding VOC exchanges in croplands, which cover a substantial portion of habitable land, is crucial. VOC fluxes result from complex interactions among biotic and abiotic processes in ecosystem components like soil and vegetation.

We present, at first, continuous BVOC fluxes measurements during a growing season in a Southern European sorghum plantation, in the agro-ecosystem of the IT-BCi ICOS site. The findings revealed that the sorghum plantation emitted oxygenated BVOCs, predominantly methanol and acetaldehyde. Self-Organizing Maps (SOM) analysis demonstrated distinct BVOC flux patterns correlating with sorghum growth stages. Additionally, SOM differentiated stressful events like plant lodging and harvest cutting based on BVOC emissions, with higher acetaldehyde emission characterizing lodged plants.

Afterwards, we tried to discern the contribution from soil and plants to the net ecosystem VOC fluxes, investigating their evolution over the season in response to physiological and environmental factors. Ecosystem-level VOC fluxes were measured employing eddy covariance micrometeorological methods copuled with the PTR-ToF-MS VOCs detection. Moreover, VOCs fluxes were measured also from soil, copuling the PTR-ToF-MS with an adapted automated chamber system, while plant VOC fluxes were sampled using cartidriges with an adapted photosynthesis measuring systems, exploring an intracanopy gradient. This research emphasizes the understanding of the ripartition of the sources and sinks of VOCs among the ecosystem compononents.

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Partitioning soil respiration in grassland on peat under different water table heights.

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Peatlands cover an estimated 21% of Ireland of which, it is estimated 350,000ha are currently under grassland management (Connolly, 2018). Due to the subsequent drainage to make the soil suitable for grass based agriculture these ecosystems emit an estimated ~8mt CO_2 eq yr^{-1}. Understanding the drivers of CO_2 and CH_4 dynamics under different water table (WT) levels is key for assessing the mitigation potential for this form of management on organic soils. Total respiration (Rtot) is the principal pathway of carbon (C) loss from an ecosystem to the atmosphere. Rtot is often measured in as one flux using eddy covariance or chamber systems but is comprised of two components, autotrophic (Ra) and heterotrophic respiration (Rh). Soil partitioning experiments are useful tools for separating respiration pathways, providing insight into the contribution of Ra and Rh in Rtot. These experiments can also provide useful data for validating process based models for GHG fluxes.

This study seeks to understand the differences and trends in Ra and Rh under different treatment types using root exclusion under different water table heights on a site in the Irish Midlands. The site has been actively rewetted due to partial drain blocking however, due to differences in elevation and peat depth the site has a variable water table across a small spatial scale. This study uses combination of automated chamber systems and weekly/biweekly smart chamber measurements (CO_2 and CH_4), coupled with ancillary measurements to quantify the contributions of Ra and Rh to Rtot under different water table heights.

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Investigation of the Suess effect in the high latitude over the last two decades – A model-data study

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Anthropogenic CO_2 emissions from fossil fuel combustion have caused an increase in oceanic DIC and a decline in $\delta^{13}C_{DIC}$ (called the Suess effect). $\delta^{13}C_{DIC}$ is thus a useful tracer to assess the oceanic uptake of anthropogenic CO_2.

Global carbon budgets have revealed a growing deviation over the last 10 to 15 years between the estimates of the ocean carbon sink based on observations and models, with the growth of the observation-based ocean CO_2 sink being larger compared to the model estimates (e.g. Friedlingstein et al., 2023). Discrepancies in the multi-decadal trend originate from all latitudes but are greatest in the Southern Ocean.

To investigate the decadal change of both DIC and $\delta^{13}C_{DIC}$ we use a hindcast simulation for 1958-2022 (NEMO-PISCES model) and compare the trends over the last two decades with observations from two French monitoring programs focusing on the high latitudes:

- surface and water column samples from OISO (Océan Indien Service d'Observation) in the South-West Indian Ocean during summer (1998-2021),
- surface samples from SURATLANT (SURveillance de l'ATLANTique) in the North Atlantic Subpolar Gyre during summer and winter (2005-2019).

Our analysis reveals some inconsistencies between simulated and observed DIC and $\delta^{13}C_{DIC}$, as well as between other simulated and observed biogeochemical parameters, whereas physical parameters are generally well reproduced by the model. Identifying the cause for this mismatch bears the potential to explain all or part of the divergence between the simulated and observed ocean carbon sink.

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Quantifying methane emissions at European scale with a special focus on Austria using inverse modelling

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

In recent years, methane (CH4) has attracted increasing scientific attention as the second most abundant anthropogenic greenhouse gas (GHG) in the atmosphere. Due to the high reduction potential and the relatively short atmospheric lifetime of around 9 years, mitigation measures can become effective within a relatively short period of time. However, the current estimates of CH4 fluxes from emission inventories are still subject to uncertainties at both global and regional scale.
An effort to reduce uncertainties from those bottom-up flux estimates is given by inverse modelling, which provides a robust tool to verify GHG emissions by combining GHG observations as well as atmospheric transport modelling and statistical optimization.
In this study, we use an inverse modelling approach to estimate CH4 fluxes at European scale for the year 2022. Additionally, we use the European in-situ observation network to explore the feasibility of reducing uncertainties in CH4 fluxes in Austria, a European country with a limited availability of stationary observations. This work is part of the Austrian ASAP18 flagship project “GHG-KIT: Keep it traceable”.
Hereby, the inverse modelling tool FLEXINVERT is used, which is based on the backward simulations of the Lagrangian particle dispersion model FLEXPART (FLEXible PARTicle). In particular, we investigate to what extent prolonged backward trajectories of 50 to 100 days contribute to better constrain the CH4 fluxes. In an attempt to estimate background concentrations as accurately as possible, we use global CH4 concentration fields obtained with the chemical transport model FLEXPART (CTM).

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Exploring the impacts of glacial meltwater on marine CO_2 uptake potential: Insights from Young Sound, NE Greenland

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Theme

7. Carbon Cycling along the Land Ocean Aquatic Continuum

Abstract Text

The global oceans mitigate climate change by sequestering approximately 25% of annually emitted anthropogenic carbon dioxide (CO_2). High latitude shelf waters, such as Greenlandic fjords, represent important sinks for CO_2 due to their distinct environmental conditions. However, global surface warming is accelerating the retreat of the Greenland ice sheet and meltwater discharge into fjord waters. This freshening of fjord ecosystems induces biogeochemical changes that impact the carbonate system and alter fjord circulation dynamics, potentially influencing future productivity and rates of CO_2 uptake. The pronounced freshwater gradients that are formed between the Greenland ice sheet and shelf waters provide useful insight into carbon cycling in a future, fresher Arctic. High resolution sampling of Young Sound, NE Greenland combined with controlled seawater-freshwater mixing experiments, sheds light on the varying effects of glacial meltwater on the marine carbon dynamics driving air-sea exchange. This multifaceted approach allows us to examine the relative physical, chemical, and biological impacts of freshwater in this ecosystem. Long term observations by the Greenland Ecosystem Monitoring (GEM) Program at the same location serve as an environmental barometer, gauging climate impacts and ecosystem shifts in the Arctic. Our dataset of pCO_2, now rounding 1.5 decades, helps to illustrate the evolution of fjord waters as a carbon sink and explain processes of freshening and modified air-sea exchange in a future Arctic.

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Quantifying uncertainties in the chamber method for measuring long-term fluxes and treatment effects: statistical issues and reproducibility

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Fluxes of greenhouse gases are typically very heterogeneous in space and time, particularly in the case of N_2O. Often we are interested in emission factors, which involves estimating the cumulative flux over a number of months. Estimating emission factors from a small sample of heterogeneous data, and propagating the uncertainties correctly is difficult. Because of this, studies which set out to examine effects of experimental treatments on fluxes and emission factors often under-estimate their statistical power (the probability of detecting an effect when it is present) and the biases from spatial heterogeneity. This results in a high false discovery rate (the probability of a p value < 0.05 being a false positive) in such experiments. High false discovery rates are one of the root causes of the reproducibility crisis, which is widely acknowledged in social and biomedical science, but less well recognised in ecology and biogeosciences. The upshot is that many published results are false, and many valid studies with less clear-cut results go unpublished. Here, we examine the extent of this problem in the domain of chamber fluxes of GHGs, focussing on N_2O. We look at the causes in terms of the uncertainties introduced by the flux measurement process, spatial upscaling, extrapolating in time. We analyse the advantages and disadvantages of automated chamber systems versus manual chamber (higher temporal coverage versus higher spatial coverage). Lastly, we make some recommendations for experimental design, and necessary sample size, and recommend a Bayesian approach, which circumvents the problem by avoiding null-hypothesis testing.

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Temporary soil waterlogging affects CO_2 flux dynamics but not the cumulative emissions

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

Increasingly variable rainfall patterns and mild winters may result in more frequent and prolonged off-season waterlogging in northern latitudes. Yet, until recently the effect of periodic anoxic conditions on carbon dioxide (CO_2) production has been overlooked in mineral upland soils increasing uncertainties in modelled CO_2 fluxes. A monolithic soil lysimeter experiment with 32 intact monoliths (l=63 cm, d=15.2 cm) from two agricultural fields (silty clay, sandy loam) in southern Finland was used to study the effect of off-season waterlogging on soil CO_2 production. During the 1.5-year study, half of the monoliths were subjected to three waterlogging episodes (48-54 days) outside the growing seasons, while the rest were maintained at 50% water filled pore space. Soil temperature, moisture and redox potential were continuously measured, and dissolved organic (DOC) and inorganic carbon (DIC) concentrations in pore water were analyzed at three soil depths (10, 30 & 50 cm). CO_2 fluxes were measured with a manual chamber. Waterlogging reduced CO_2 fluxes during saturation but increased the DIC in soil pore water indicating an accumulation of CO_2 in the soil. Thus, the reduced CO_2 fluxes were not only due to reduced respiration but also to hindered diffusion and release of CO_2 from water saturated soil. Drainage induced a rapid pulse in CO_2 fluxes in sandy loam and a more gradually increased CO_2 release in s lowly drying silty clay. The increase in CO_2 fluxes after drainage roughly equaled that of the decrease during saturation and hence, waterlogging did not significantly alter cumulative CO_2 emissions.

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Conversion or Conservation: Significance of Forest and Heathland Ecosystem in an Ecological Balance.

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Theme

13. In situ data for climate and other environmental services and policy support

Abstract Text

Conversion of forest into heathland is increasingly being considered as a new paradigm for heathland ecosystem restoration among scientists and policy makers. However, the potential of temperate heathlands in Western Europe for climate mitigation has little been studied and should be evaluated through continuous monitoring of greenhouse gas (GHG) emissions using the eddy covariance method. In order to assess the impact of ecosystem conversion, analysis of the intricate carbon and water dynamics of both ecosystems is imperative. Carbon and water fluxes provide insight into ecosystem services such as carbon sequestration, climate and water regulation. In addition, water exchange and storage determines the ecosystem resilience to climatic extremes. This study, aiming at analyzing carbon and water fluxes of forest and heathland, is carried out at two of ICOS ecosystem stations: "Maasmechelen" is a dry heathland and "Brasschaat" is a Scots pine dominated forest. Both are located in Flanders, Belgium. The results of the study demonstrate the potential of both ecosystem for enhancing productivity and mitigating atmospheric CO_2 emissions in a global change scenario. This study therefore provides an evidence based approach in examining the trade-offs and benefits associated with ecosystem conversion, and can assist in determining effective management strategies.

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Carbon sinks in prodeltaic sediments : a double-trigger environment

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Theme

7. Carbon Cycling along the Land Ocean Aquatic Continuum

Abstract Text

Coastal benthic ecosystems with high sedimentation rates have been known for hosting large sinks of carbon through the burial of organic matter. In river-dominated ocean margins (RiOMar), the origin of the buried organic matter is dominated by terrestrial debris in marine environments, highlighting the linkage between continents and oceans, the two major reservoirs at the Earth surface. Consequently, river deltas represent a prominent carbon sink in the world ocean: despite its 0.3% of the surface area, it represents 40% of organic carbon burial in the entire ocean sediments. A new approach, based on differential bathymetry, will be presented for calculating the carbon balance in the Rhône River prodelta.

Conversely, prodeltaic sediments are very active organic carbon recycling zones which give rise to the double-trigger carbon sink. These organic-rich sediments undergo intense anoxic diagenesis producing substantial amounts of total alkalinity (TA). In aquatic systems, changes in alkalinity can generate sinks of CO_2 originating from the atmosphere or can limit the efflux of dissolved inorganic carbon (DIC) associated with organic matter mineralization. High-accumulation sediments have the potential to sequester reduced products from anoxic diagenesis, such as FeS, in deep layers leading to the generation of TA fluxes to the coastal bottom waters. In this presentation, the theoretical framework relating TAfluxes to the anoxic processes will be emphasized together with an example in the Rhône prodelta sediments. The DIC/TA ratio amounting from 0.5 to 1 greatly limit the acidification potential of the released DIC without creating an additional sink for atmospheric CO_2.

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Enhancing Constraints on Atmospheric Nuclear $^{14}CO_2$ Contributions in Europe to Improve Continental $^{14}CO_2$-based Fossil Fuel Estimates

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Since fossil fuels lack radiocarbon (^{14}C), the dilution of the $^{14}C/C$ ratio in atmospheric CO_2 can be used to estimate recently added fossil fuel CO_2 ($ffCO_2$). However, variations in this ratio are also caused by $^{14}CO_2$ discharges from nuclear power plants and nuclear fuel reprocessing facilities, which may mask a significant share of the $ffCO_2$ signal on regional and continental scales. The unavailability of temporally fine-scale $^{14}CO_2$ discharge data from the nuclear facilities increases the uncertainty in $^{14}CO_2$-based $ffCO_2$ estimates. The European Commission's Radioactive Discharges Database (RADD) publicly provides data on annual total nuclear ^{14}C discharges for most facilities located in the European Union. For a subset of nuclear power plants, two-week cumulative ^{14}C discharge observations were provided on a confidential basis from the operators. Here, we explore the possibility of enhancing the RADD discharge time resolution by merging the annual information with publicly available high-resolution electricity output of nuclear power plants, using the knowledge gained from the subset of two-week cumulative ^{14}C discharge observations. In addition to improving the temporal resolution, we compare two approaches to model nuclear $^{14}CO_2$ contributions at ICOS class 1 sites using either Lagrangian footprint or Gaussian plume modelling. Our ultimate goal is to better assess the uncertainties associated with nuclear contributions and to improve their correction factors in the $^{14}CO_2$-based fossil fuel estimates.

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Long term flux measurements of carbon dioxide and methane over a small boreal lake using eddy covariance technique

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

Advancing our understanding on physical and biogeochemical processes controlling turbulent exchange of energy, carbon dioxide (CO_2), methane (CH_4) and other trace gases across lacustrine systems is crucial in order to improve climate and weather forecast models. Lakes are capable of processing large amounts of organic carbon of terrestrial origin, and their importance in landscape carbon cycle and climate change issues is well recognized. Nevertheless, the amount of CO_2 and CH_4 released into the atmosphere is still uncertain.

Here, we investigate the temporal dynamics of CO_2 and CH_4 exchange using eleven years (for CO_2) and three years (for CH_4) of eddy covariance flux measurements over the Lake Kuivajärvi, a small boreal lake in southern Finland.

The lake ecosystem acted mostly as a net CO_2 source (0.42±1.56 mmol m^{-2} s^{-1}) throughout the ice-free periods and had a relatively high interannual variability when compared to the surrounding forests and wetlands. On average, the lake is a net source of CH_4 (0.63±2.44 nmol m^{-2} s^{-1}), but the measured annual emissions are lower than for CO_2, revealing that most of the CH_4 produced at the lake bottom is oxidized in the water column. Carbon dioxide and methane emissions are largely affected by the weather forcing through the effects of wind shear and nocturnal water cooling, which deepens the mixed layer and enhances gas exchange at the air-water interface.

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Advancements in Detection and Quantification Techniques of Methane Emissions at site level using UAV

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Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

Methane (CH_4) is the second most important anthropogenic greenhouse gas. Reducing CH_4 emissions is necessary to mitigate climate change. The potential for CH_4 emissions mitigation is strongly linked with improvements on individual sites, be it industrial sites (natural gas), landfills or farms. Therefore, the reliability of tools to identify and monitor emissions at site level is urgent.

Methodologies for methane measurement have evolved over the past two decades, including ground-based, mobile, and remote-sensing techniques utilizing aircraft, unmanned aerial vehicles (UAVs), and satellites. Owing to their ease of mobility, UAVs enable the quantification of point and facility-scale sources, where conventional methods may fall short (Liu et al., AMT 2024). We developed a new UAV-CH_4 system exploiting an ABB LGR GLA131 and 3D wind measurements on-board a high-endurance octocopter platform with advanced autopilot capabilities. The "CH4LKIDIQY" campaign conducted in Nicosia in January 2024, aimed to assess the capability of the UAV-based system to detect a CH_4 source during controlled-release experiments. The on-board gas analyser successfully detected the tracer gas at low release rates (0.15 kg/h) below a 5-meter height above the emission point.

Our investigation extended to quantifying CH_4 emissions from a cattle farm in Orounda, Cyprus, utilizing the same UAV-based system. Data collected mapped in detail the CH_4 plume dispersion downwind the farm with concentration variations during multiple flights. These findings significantly contribute to understanding the dispersion of CH_4 emissions, improving quantification methodologies. This work will ultimately contribute to inform strategies to reduce site-level methane emissions and mitigate climate change.

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New insights into subsurface pCO_2 gradients and flux estimates under extreme conditions enabled by the Waveglider platform

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Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

The development and evaluation of new fit-for-purpose pCO_2 measuring systems capable of performing high-quality measurements is a cornerstone for expanding the number, type and geographical coverage of observations, which contribute to closing the existing observational and knowledge gaps in CO_2 fluxes. New measurements reduce uncertainties in models and data products that use machine learning to fill observational gaps (Behncke et al., 2024) and help resolve air-sea fluxes under extreme wind events such as hurricanes and tropical cyclones.

Conventionally, air-sea CO_2 flux is calculated using surface data from the underway systems on ships of opportunity (SOOP), assuming homogeneity in the top 10 m of the water column. This assumption was recently challenged due to biotically and abiotically driven surface gradients (e.g. Watson et al., 2020).

Through industry-academia collaboration, we integrated CO2 Pro-CV pCO_2 sensors into a Waveglider platform. Simultaneous measurements at the surface and a depth of 4m using two cross-calibrated instruments were used to explore the near-surface pCO_2 gradient and its variability on the Scotian Shelf over 28 days in the spring of 2022. We also analyzed data from a deployment on the continental shelf south of Nova Scotia during Hurricane Fiona in mid-September 2022, along with complementary measurements from a SeaExplorer glider. The Waveglider carried a suite of sensors measuring temperature, salinity, dissolved oxygen, pCO_2, pH, total dissolved gas pressure, wind speed and wave height, and atmospheric pressure, resulting in a uniquely rich data set to analyze air-sea fluxes and the hurricane-induced changes in ocean biogeochemistry.

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From Science to Service: Leveraging Urban CO_2 Monitoring for Actionable Science-based Policymaking - Insights from Paris Case Studies

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Theme

12. Translating Scientific CO2 Emission Research into City Services

Abstract Text

Transitioning the state-of-the-art monitoring of urban CO_2 emissions from a scientific endeavor to a municipal service could offer significant advantages. It not only supports cities to build healthier, more resilient, and sustainable communities but also contributes to the fight against climate change. Currently, cities still face technical challenges to establish an operational capability able to bridge scientific findings and practical implementation. We conducted several case studies in Paris to evaluate how public policies implemented by local authorities affect CO_2 emissions. The analyses combine a high-resolution CO_2 emissions inventory, various open-source activity data, and atmospheric measurements with urban climate policies. Results show that the Paris Respire initiative, which designates restricted zones to promote soft mobility, led to a reduction in traffic CO_2 emissions varying from 39% to 56% across different zones. On car-free days in Paris, traffic CO_2 emissions can decrease by up to 25.6%. The Rue de Rivoli Cycle Path led to a 49% reduction in local traffic CO_2 emissions when comparing the years 2022 and 2018. Moreover, we investigate how cities can address two key goals: (1) understanding policy impacts across different spatiotemporal scales and (2) continually adapting the territory for science-based policy evaluation. Our findings highlight the importance of recognizing distinct patterns and behaviors as significant indicators for policymakers, urging consideration of both direct and indirect effects over short and long terms. We believe that demonstrating the integration of scientific approaches in Paris could serve as a model, assisting other cities to reach their respective climate objectives.

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Warming and cooling effect based on CO2 fluxes and albedo changes in different N:P ratios in Mediterranean savanna ecosystem

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Changes in both greenhouse gas fluxes and albedo are associated with biogeochemical cycles and biophysical properties that influence net radiative forcing (RF) of terrestrial ecosystems. Ecosystem-atmosphere interactions of semi-arid savanna ecosystems are complicated by the tree-grass coexistence. This study investigates net warming and cooling effects on the surface (local scale) and top of atmosphere (global scale) due to differences in nitrogen (N) and phosphorus (P) ratio changed by fertilisation. We used a long-term dataset (2014-2023) collected at three co-located eddy-covariance sites in a Mediterranean savanna, Spain (i.e., ES_LMa, ES_LM1, and ES_LM2 representing control, N, and N+P added, respectively). Locally, we observed cooler surface temperatures (Tsurf) (across ecosystem, tree, and grass layers) of -0.08 to -0.35 °C at ES_LM1 and warmer Tsurf of -0.09 to 1.43 °C at ES_LM2 compared to control. We calculated differences in net RF between the sites considering changes in both albedo (Δα) and net ecosystem exchange (ΔNEE). The results indicate that both fertilisation treatments increased ecosystem albedo, especially during summer periods (Δα = 0.015 to 0.021) and enhanced ecosystem carbon sink capacity (ΔNEE =-63.12 to -56.17 $gCm^{-2}yr^{-1}$). Overall, net RF changes due to fertilisation were dominated by Δα, leading to a net cooling effect (-1.04±0.33 and -0.41±0.59 $10^{-14}Wm^{-2}(global)m^{-2}$, respectively for ES_LM1 and ES_LM2). Therefore, fertilisation treatments in savannas can alter Tsurf and net RF. We aim to further assess which eco-physiological factors contributed to Tsurf dynamics of ecosystem, tree, and grass levels.

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Volatile organic compounds emission and secondary organic aerosol formation from agricultural recycling of organic waste products

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Theme

2. Exchange of reactive gases and aerosols between the land surface and the atmosphere in natural and managed ecosystems

Abstract Text

Agriculture with the use of fertilizers is known to emit volatile organic compounds (VOC) that have the potential in forming secondary organic aerosols (SOA) through their reactions with atmospheric photo-oxidants. In a societal context that encourages the recycling of Organic Waste Products (OWP) in agriculture, the comparative effects of mineral fertilizers and OWP on these emissions are of particular interest. The objective of this project is to elucidate the mechanisms of production and degradation of VOC emitted by different OWP and to quantify the potential for SOA formation. It addresses this fundamental problem in atmospheric science by combining laboratory experiments and field measurements. It also aims to model this SOA formation in order to assess the environmental impacts in an agricultural landscape and provide recommendations to preserve air quality following the use of organic and mineral fertilizers.

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Lessons for coastal ocean alkalinity enhancement in a fully-coupled Earth system model

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Theme

8. Enhancing the ocean carbon sink: the science, verification, and governance of marine-based carbon dioxide removal (mCDR)

Abstract Text

Reducing carbon dioxide (CO2) emissions from certain activity sectors will be challenging, and carbon dioxide removal (CDR) interventions will be needed to achieve "net-zero" before the end of the 21st century. One of these, ocean alkalinity enhancement (OAE), proposes dissolving basic minerals into the ocean to act as a source of total alkalinity (TA) and to permanently increase its buffering capacity for CO2. However, the slow dissolution of these minerals risks them sinking away from contact with the atmosphere and reducing the efficiency of OAE. To counter this, coastal OAE retains the TA produced near the surface using the shallow seafloor of the ocean's readily-accessible continental shelves. Here, we investigate this using a state-of-the-art Earth system model, UKESM1, configured to add TA at the temperature-dependent dissolution rate of olivine. Evaluation across the 21st century quantifies ocean CO2 uptake driven by OAE, its redistribution within the ocean, and the general efficiency rate relative to the TA added. The fraction of the CO2 uptake that occurs in the OAE operation area, and the wider balance of the Earth system's carbon cycle and climate are also examined.

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Estimation of Terrestrial Vegetation Gross Primary Productivity (GPP) using the Quantum Yield Model and Sentinel-3 Data: The QY GPP Product.

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Gross primary productivity (GPP), the amount of carbon dioxide (CO_2) fixed by plants through photosynthesis per unit area per unit time, plays a critical role in reducing the rate of build-up of anthropogenic carbon emissions in the atmosphere. However, accurate estimation of GPP is still a challenge due to its high spatial and temporal variability. The increasing availability of satellite data offers an opportunity to develop new methods and products to quantify GPP across the globe. Here we present a new global GPP product generated using the Quantum Yield (QY) model and Sentinel-3 data. The QY model is unique in its use of photosynthetic pathway (C_3/C_4) quantum yield terms to quantify the rate at which plants convert absorbed energy into dry matter. Evaluation of the new QY-GPP product across various biomes, using eddy covariance flux tower data from ICOS and Ameriflux networks, showed that it corresponds well with *in-situ* data(i.e.,R^2= 0.72; RMSE=3.16gCm^{-2}day^{-1}; MAE=2.5 gCm^{-2}day^{-1} and Bias =1.39; n=2350). Additionally, when compared with two operational satellite-based GPP products (i.e., Copernicus Global Land Service Gross Dry Matter Productivity-CGLS GDMP and MOD17 GPP), the GPP predictions from the QY model explained a higher variability of *in-situ* measurements (i.e., QY GPP: R^2= 0.72; CGLS GDMP GPP: R^2 = 0.62 and MOD17 GPP: R^2= 0.56). With the expected availability of Sentinel 3 data into the next decades, the QY GPP product offers a new source of data that can be used to characterise GPP and its dynamics across the globe.

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Carbon Balance and Flux Dynamics at the FR-Grignon ICOS Site: A 2005-2023 Analysis

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

As climate change urgency escalates, recognising the role of agricultural lands in carbon management for mitigation strategies becomes crucial. This 18-year study at the Grignon site, a labelled site within the Integrated Carbon Observation System (ICOS) network, located 40 km west of Paris, France, provides a comprehensive analysis of carbon flux dynamics affected by crop rotations and agricultural practices. Utilising the eddy covariance method, we measured net ecosystem exchange (NEE) and evaluated gross primary production (GPP), and ecosystem respiration (Reco). We compiled imported and exported carbon as organic fertiliser and harvest and evaluated carbon loss by leaching, to assess the carbon balance at the Grignon agricultural site, which can be compared to the carbon stock change measured between 2005 and 2019 and the soil carbon balance model AMG.

Our investigation focused on harmonising heterogeneous data over time, encompassing the evolution of methodologies, analysers, and data sources (farmer-reported vs. biomass measurements). This revealed a shift towards the site becoming a carbon emitter, with notable inter-annual variability mainly driven by carbon import and export dynamics. We compared different methodologies for gap-filling and consolidating the imports and exports data using the available information (farmer, biomass sampling). The spatial inhomogeneity of the biomass production in the field was also investigated using high-resolution remote sensing.

This study underlines the importance of sustainable farming practices for enhancing carbon sequestration and reducing emissions. Such practices are essential for informing policy and promoting climate-resilient agricultural strategies, highlighting informed, sustainable farming's role in combating climate change.

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Partitioning photosynthesis limitations of potato during edaphic water stress

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

Identifying the physiological processes that limit gross primary production (GPP) of crops during water stress is crucial for ensuring food security. However, the influence of soil water availability on GPP limitation is still not fully understood. We combined gas exchange and fluorescence measurements at the ecosystem scale (eddy covariance) and leaf scale to investigate the origins of photosynthesis limitations of potato (*Solanum Tuberosum*) under soil water availability-limiting conditions in central Belgium. We aimed to determine whether GPP limitations originated from stomatal (decrease in the stomatal sensitivity to photosynthesis g_1) or non-stomatal factors (decrease in the maximum carboxylation rate V_{cmax} or in the mesophyll conductance g_m). The analysis of eddy covariance data of four consecutive growing seasons of potato at the Lonzée ICOS station (BE-Lon) shows a consistent effect of non-stomatal factors on GPP. Non-stomatal factors can be partition between g_m or V_{cmax} when joint gas exchange and chlorophyll fluorescence measurements are performed. To that end, we set up a drought experiment and measured the response of gas exchange and chlorophyll fluorescence at the leaf level to the decrease in REW. Stomatal and mesophyll conductance were the first factors to be reduced while V_{cmax} decreased from a lower REW threshold. Limitation analysis showed that g_m accounted for most of the decrease in stomatal conductance and photosynthesis. We emphasize the need to consider the effects of drought on mesophyll conductance to reduce uncertainties when modeling photosynthesis and transpiration of potato. Revisiting the partitioning methods to fully unravel the physiological controls on carbon and water fluxes during water stress is needed.

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Continuous in-situ measurements of atmospheric CH_4 at an urban-industrial station: a two-year analysis of CH_4 spatio-temporal variability and sources identification using co-emitted species

Pauline Bosio[1], Irène XUEREF-REMY[1], Pierre-Éric Blanc[2], Aurélie Riandet[3], Grégory Gille[4], Alexandre Armengaud[4], Sonia Oppo[4]

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Theme

1. Isotopes and other tracers for studies of methane sources and sinks

Abstract Text

Methane (CH_4) is the second most important direct anthropogenic greenhouse gas, with a lifetime about 10 times shorter than carbon dioxide (CO_2) and a warming potential 80 times greater over a 20-year period. Reducing CH_4 emissions therefore represents a lever for rapid action on global warming. The Sud-PACA region (south-eastern France), classified by IPCC as a climate "hotspot", is part of these efforts to reduce CH_4 emissions, with the aim of achieving carbon neutrality by 2050. To reach this goal, reducing uncertainties of regional CH_4 emissions is therefore essential. Over 50% of Sud-PACA methane sources are estimated by the ATMOSUD regional inventory (https://cigale.atmosud.org/) to be located in the southwestern part of the region. This area is highly urbanized and industrialized as it comprises France's second-largest industrial zone. However, the ATMOSUD inventory has never been assessed independently. To fill this gap and to better characterize anthropogenic sources of CH_4 in this area, a top-down approach was developed, based on a new atmospheric CH_4 monitoring station consisting of a Picarro Cavity Ring-Down Spectroscopy analyzer and a meteorological station installed in May 2021 as part of the ANR COol-AMmetropolis project at Port-de-Bouc. We will present the diurnal, synoptic and seasonal variability of atmospheric CH_4 at PdB, an analysis of the relationships between CH_4, CO and CO_2, a source identification study using $^{13}CH_4$ isotopic signatures and a comparison with the literature. These data represent the first measurements of CH_4 in this industrial area and will also be used to independently verify regional inventories.

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Crop gross primary production and yield estimation from Sentinel-2 data using a light use efficiency model

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Theme

14. Leveraging Direct Flux Measurements Beyond Academia for Real-World Applications

Abstract Text

Agricultural fields globally can reduce 10% of greenhouse gas emissions by absorbing CO_2 during photosynthesis (Gross Primary Production: GPP) process. It is indispensable to precisely capture the spatiotemporal dynamics of crop GPP over the field. A remote sensing (RS) based Light Use Efficiency (LUE) model can provide a high-resolution spatiotemporal estimate of crop GPP, which can be further linked to the quality-assured estimate of crop yield. At field scale, the accuracy of LUE model depends on how well the spatiotemporal dynamics of land surface properties such as crop Leaf Area Index (LAI) are captured. In this study, we retrieved 10m resolution LAI from Sentinel-2 satellite data by implementing a hybrid inversion approach that combines radiative transfer model PROSAIL with machine learning. We retrieved LAI during the growing seasons of winter wheat, rapeseed, and barley from 2016 to 2019 at the ICOS agriculture field in Oensingen, Switzerland. The retrieved LAI were further fed into the LUE model to simulate GPP at 10 m resolution. The statistical relationship between simulated GPP and flux tower GPP demonstrated by Kling-Gupta efficiency (KGE) indicated the reasonable accuracy of the LUE model. The simulated GPP over the growing period of each crop was further converted into crop yield by utilizing crop-specific harvest index, moisture content, and root-to-aboveground biomass ratio. The percentage difference between the measured and estimated yield varied from 2% to 20%. Our results demonstrated that LUE is an essential class of RS data-driven model for estimating GPP and crop yield to address food security.

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Evaluating GHGSat total column methane measurements using nested WRF LES simulations

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Methane (CH_4) is an efficient target for rapid climate change mitigation due to its stronger radiative forcing compared to carbon dioxide (CO_2). To better understand anthropogenic CH_4 emissions sources, high spatial resolution satellite instruments were launched by GHGSat during recent years to measure methane emitted from relatively large point and area sources. The objective of this study is to test the performance of GHGSat's measurements of CH_4 plumes at a landfill in Indianapolis, Indiana, which is a well-studied CH_4 emission source. GHGSat total column CH_4 measurements are evaluated against plumes simulated using the Weather Research and Forecasting (WRF) model nested from mesoscale to large-eddy simulation (LES) domains. A total of six one-way nested domains are used to simulate dispersion of tracers in the turbulent atmospheric boundary layer with realistic mesoscale forcing. The 37 m horizontal grid spacing of the inner most domain is comparable to the 30 m spatial resolution of GHGSat. With landfill emissions represented as a constant, continuous source of tracers, dispersion results in the inner most domain are compared to GHGSat observed CH_4 plumes. The analyses performed for a total of ten different days show considerable day-to-day variation and can be grouped roughly as: 1) excellent agreement in plume location and concentration; 2) plumes of similar concentrations but dislocated; and 3) plumes not observed by GHGSat. The causes for these discrepancies will be investigated using available observations of mean and turbulent winds and eddy-covariance measurements of CH_4 fluxes.

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Towards a pan-African Research Infrastructure for Atmospheric, Climate and Ecosystem Services: Three Decades of International Collaboration in Kenya

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Theme

13. In situ data for climate and other environmental services and policy support

Abstract Text

Consistent, reliable and long-term data – documenting variability and trends of atmospheric composition and land-atmosphere interactions – are needed across the globe to address climate change and health. Large regions remain undersampled. This is especially true for Africa, which already experiences the impacts of climate change at a large scale. Under the auspices of the WMO GAW and GCOS Programmes and NASA's SHADOZ project, Switzerland has collaborated with the Kenyan Meteorological Department (KMD) since 1996 to support atmospheric observations in Kenya. This has resulted in regular ozone soundings in Nairobi and continuous observations of gases and aerosols at the Global Atmosphere Watch (GAW) station Mount Kenya. Furthermore, several eddy-covariance flux towers were installed to observe the net exchange of CO_2, CH_4 and water vapour from diverse ecosystems in Kenya. More recently, the Horizon Europe project KADI (Knowledge and climate services from an African observation and Data research Infrastructure) has provided a pan-African context to these activities to connect distributed and sparse activities into an integrated research infrastructure. Quality control, hardware acquisition, training, and data analysis are key elements of the collaboration.

We will share results obtained and experience gained during the long-lasting partnership and provide lessons learned. This is critical information paving the way towards designing comprehensive monitoring and research capabilities for climate change observations, as well as the provision of climate and air quality information and services across Africa.

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How reliable are process-based radon flux maps? Results from a radon inversion in Europe

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Inverse modeling provides a powerful tool to estimate and verify greenhouse gas emissions on regional to global scales using independent atmospheric observations. However, its success strongly relies on a proper description of atmospheric transport and mixing processes. In fact, atmospheric transport modeling is responsible for the largest uncertainties of this method, which are also difficult to quantify. Therefore, usually only the observations during well-mixed atmospheric conditions (e.g., in the afternoon), that are well represented in the model, are used to constrain the emissions.

The radioactive noble gas radon (half-life of 3.8 days) is mainly released from continental soils and shows a strong vertical gradient in the atmosphere. It can thus be used as a tracer for atmospheric mixing. The comparison between modelled and measured radon activity concentrations could therefore pave the way to a more reliable quantification of transport model uncertainties and to the exploration of non-afternoon observations with inverse models. However, this relies on well-calibrated radon measurements and accurate radon fluxes.

In this study we aim to evaluate the accuracy of process-based radon flux maps for Europe. Their reliability depends on the accuracy of the underlying soil moisture products. We performed a radon inversion to validate these a-priori radon fluxes. We show that our radon inversion yields robust flux estimates for Central Europe, which are mainly data driven but have a higher variability than the process-based fluxes. These results could be used to improve the description of radon exhalation from the soil and thus the radon flux maps themselves.

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Low-cost sensors for spatially distributed CO_2 measurements through Arctic snowpacks

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Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

Although historically considered negligible, wintertime CO_2 emissions from the Arctic tundra are now thought to make up a notable proportion of the annual carbon budget. However, poor availability of wintertime measurements, largely due to logistical and methodological measurement constraints limit our capacity to estimate the magnitude and variability of CO_2 emissions. Here we present CO_2 measurements from new experimental low-cost sensors alongside in-situ profiles of CO_2 concentrations and isotope ratios to better account for temporal and spatial variability in CO_2 flux at Trail Valley Creek, NWT, Canada during late winter of 2021-2022 and 2022-2023. The experimental low-cost sensors provide very high (sub-minute) resolution timeseries of CO_2 concentrations, which we use to derive fluxes for different land cover types. CO_2 fluxes measured using both the experimental low-cost sensors and established labour-intensive gas profiling technique show similar magnitudes of CO_2 emission. We find spatial variability in land cover and snow depth to impact CO_2 fluxes. Across all sites, we typically find concentrations of CO_2 at the base of the snowpack greater than atmospheric concentrations, indicative of CO_2 emission from frozen soil. More negative carbon isotope ratios are typically found at the base of the snowpack, indicating soil respiration as a source of CO_2 at the base of the snowpack. This CO_2 emission relates to gas temperatures in a manner consistent with studies which have compiled data from across the Pan-Arctic using a variety of measurement techniques, showing potential for the further development and deployment of these sensors.

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Grazing vs Silage Cuts: A comparison of the carbon and net greenhouse gas balance of an intensively managed grassland at the field scale.

Rachael Murphy

Teagasc, Johnstown, Ireland. Teagasc Climate Centre, Johnstown, Ireland

Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

In 2019 and 2020, we assessed the field scale net carbon and greenhouse gas balance (NGHGB) of an intensively managed temperate grassland that is part of the National Agricultural Soil Carbon Observatory (NASCO) – a network of 28 eddy covariance (EC) sites measuring GHGs over different land-uses, managements and soil types. In 2019 the field site was under a cut management for silage production and in 2020 the field site was strip-grazed. Imports and exports were quantified through management data and EC measurements of ecosystem-scale CO_2 and N_2O fluxes. Literature values were used to estimate C imports and exports, and enteric CH_4 fluxes where measurements were not available. The EC measured net ecosystem exchange of CO_2 showed that the field site was a sink of C under both managements. Greater C returns were observed under the grazing system through excreta deposition compared to the silage cut system which didn't receive organic fertilization. Large C exports from biomass removals were measured from both systems. N_2O emissions were higher under the grazing system compared to the cut system, and estimated CH_4 emissions from enteric fermentation were circa twice as large as N_2O emissions measured during grazing. In both years the net C sink of the grassland (g CO_2eq m^{-2} yr^{-1}) was not significantly different from zero, yielding a NGHGB of -82 ± 574 and 88 ± 507 for the cut and grazing management respectively. NASCO is funded by the Department of Agriculture Food and Marine, the Dairy Levy Trust and co-funded by Terrain-AI.

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Blue Boat: A Low-cost Autonomous Surface Vehicle for Measuring Carbonate System Parameters in Surface Waters

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Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

High spatiotemporal resolution carbonate system measurements are crucial for informing models for accurate estimations of air-sea CO_2 fluxes and representation of biogeochemical processes (Resplandy, 2024). Shelf regions and coastal areas are disproportionate in their impact on global CO_2 dynamics (Fennel, 2019) and require increased measurement coverage to sufficiently resolve their variable fluxes.

High frequency monitoring in coastal areas is conventionally accomplished using fixed moorings and buoys outfitted with a suite of sensors. However, the fixed locations of these systems severely limit measurements in the spatial plane. Furthermore, accessibility and rapid turnaround of the sensors is always not possible without ship access. Compact, autonomous surface vehicles (ASVs) provide easy-access platforms for in-situ sensors and increased deployment flexibility.

In this study, we present the customization and deployment of the Blue Boat from Blue Robotics: a low-cost autonomous surface vehicle that was outfitted with a suite of sensors for carbonate system parameters: pH, temperature, conductivity, and the partial pressure of CO_2 (pCO_2). The boat was deployed in the Bedford Basin/Halifax Harbour to investigate variability of pCO_2 in surface waters before and during the dosing phase of a local ocean alkalinity enhancement (OAE) trial. The Basin offers an ideal testing ground due to its dynamic hydrographic and biogeochemical conditions and the ongoing OAE trial.

The selection of sensors provided a unique data-set for understanding surface carbon variability, and revealed significant spatial pCO_2 gradients , thereby highlighting the importance and potential of vehicle-based, high-resolution monitoring.

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Understanding Ozone Dynamics in Periurban Mediterranean Forests: Insights from Multiannual Flux Measurements

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Theme

2. Exchange of reactive gases and aerosols between the land surface and the atmosphere in natural and managed ecosystems

Abstract Text

Tropospheric ozone (O_3) is harmful to plants, causing leaf damage, reduced photosynthesis rates, and inhibited growth. Urban areas, abundant with anthropogenic O_3 precursors, significantly contribute to O_3 formation, posing a particular risk to periurban Mediterranean forests. This risk is especially exacerbated by the elevated temperatures typical of Mediterranean regions. Multiannual measurements of ozone (O_3) fluxes have been conducted from 2012 to the present in the Oak Holm Forest of Castelporziano Estate, a coastal forest located 25 km from downtown Rome, Italy, class 1 ICOS site. These measurements were carried out utilizing the eddy covariance technique on a 21-meter-high tower. Ozone (O_3) fluxes were separated into stomatal and non-stomatal components using the evaporative/resistive method, and Eddy Covariance water fluxes. Utilizing this extensive dataset of ozone fluxes, the current study aims to identify seasonal patterns in ozone stomatal fluxes while addressing the factors influencing their fluctuations. It will also consider the year-to-year variability of ozone fluxes based on climatic conditions, alongside the variability of ozone detoxification efficiency, expressed as the ratio between ozone stomatal flux and carbon dioxide flux, on an annual basis. This work benefits from long-term flux measurements and ancillary measurements performed in the frame of ICOS Italy network.

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Snow as an insurance: winter snowpack protects alpine grassland from early summer drought

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

Grasslands cover up to 70% of the agricultural area in Switzerland, including many (sub)alpine elevations. Over the past decades, snow cover in the Alps has been decreasing due to climate warming. Although diminished snow cover may prompt an earlier growing season start and elevated temperatures could enhance productivity, snowpack significantly impacts grassland water availability, particularly in the early growing season.

In this study, the net ecosystem exchange of CO_2 (NEE) was measured with the eddy covariance technique over an extensively managed alpine grassland (2000 m.a.s.l) in Switzerland. The grassland serves as a summer pasture for cattle for approximately three months annually. Data collection spanned nine summers (2006-2014) and nine full years (2015-2023). The grassland acted as a net CO_2 sink in all full years, with cumulative NEE varying between -43 and -265 gCm^{-2}. A smaller winter snowpack was linked to earlier snowmelt and growing season onset but also to a decreased net ecosystem CO_2 sink. We found that the summertime maximum CO_2 sink (minimum daily NEE) partially depends on the amount of snow in the previous winter: the higher the snowpack, the higher the CO_2 sink (more negative daily NEE). In addition, dry atmospheric conditions in the early summer (i.e., June) did not reduce CO_2 uptake rate partially due to high winter snowpack. We also observed temporal variations in the importance of radiation, soil moisture and temperature on NEE, with soil moisture being the second most important driver after radiation from the snowmelt period to early growing season (April-June).

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Soil Texture Modulates Ecosystem Water Limitation: From Local to Global Importance of Soil and Atmospheric Drought on Transpiration and Photosynthesis

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

At a critical soil water content (θ_{crit}), plants downregulate transpiration rate and photosynthesis, shifting terrestrial ecosystems from energy to water limitation and potentially from carbon sink to carbon source. This threshold value θ_{crit} is thus central to assessing soil and atmospheric drought impacts on vegetation and the associated feedback to carbon and hydrological cycle. However, the mechanisms behind θ_{crit} remain poorly quantified, particularly at the ecosystem scale. By applying a soil-plant hydraulic model to tree- and ecosystem-scale observations of θ_{crit} across climates and biomes, we show the global importance of soil-specific hydraulic conductivity for transpiration and photosynthesis. The underlying concept to simulate θ_{crit} assumes that ecosystem water limitation is triggered by a loss in soil or plant hydraulic conductivity. While the relative importance of soil and plant hydraulic conductivity is mechanistically linked to the relative importance of atmospheric and soil drought, these relative importances depend on the soil. Here we find a strong soil texture dependence of θ_{crit}, and more importantly of the corresponding critical soil water potential (ψ_{crit}). In coarse textured soils, ψ_{crit} is small reflecting the steep drop in soil hydraulic conductivity. In these soils, the relative importance of the soil is therefore emphasized compared to fine textured soils, where atmospheric drought and plant hydraulic limitation become comparably more important. Although vegetation-atmosphere exchanges are driven by atmospheric conditions and mediated by plant adjustments, their fate is ultimately soil-dependent. This implies that a widespread increase in atmospheric water demand may exacerbate plant water stress more than previously assumed.

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GEORGE roadmap towards marine data interoperability of 3 ERICs (EMSO – Euro-Argo – ICOS).

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Theme

17. Best Practices in the landscape of Research Infrastructures: Cooperation, Co-location and other lessons learned

Abstract Text

The need to have scientific information, easily available and easy to digest *across* Research Infrastructures is a necessity rather than a nice-to-have. Development of new technologies and sensors, the complexity of integrated observation systems, and the advances in data science make this a must-have. A working term that describes this is “Interoperability” within the concept of the FAIR principles. Interoperability should not be seen as a Boolean checkbox, nor a gradient scoring the "proximity to completion"; it should be measured in the accumulated "cost of use" of any shared dataset or service: the required effort to tame these various sources leading to new insights. Lowering that cost is the responsibility of the producers of these digital objects declared to be interoperable, and of the community to arrive at sufficient commonalities towards an interoperable "status quo".

The GEORGE project brings together three Research Infrastructures with a common denominator in ocean observations: EMSO, Euro-Argo, ICOS, covering the European Seas.

Within GEORGE and following the legacy of projects such as ENVRI-FAIR, we work on how to make our data and services interoperable not just between RIs and to the already-in-the-know, but across RIs and to the don’t-know. The aim is to lower the barriers by achieving interoperability at a machine-to-machine level. This can leverage observations into research and innovative outcomes that support societal needs to comprehend, adapt to, and mitigate global environmental change. The work presented includes tests, findings and recommendations on how to achieve the above.

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Impacts of warm autumn on carbon sequestration: insights from mature hemiboreal coniferous forest.

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

Mature boreal forests play an important role in the global carbon cycle due to their extensive area and ability to sequester a considerable amount of atmospheric carbon dioxide (CO_2). They are generally stable ecosystems that function as carbon sinks, however, their sink capacity is vulnerable to the impact of extreme weather conditions. In this study, we aim to investigate the interannual carbon dynamics of a mature coniferous forest (70-230-year-old) located in Estonia in the hemiboreal zone. Over an eight-year period (2016-2023), the forest shifted from a carbon sink (mean net ecosystem productivity (NEP) of 237.76 ± 51.90 g C m^{-2} $year^{-1}$) to a carbon-neutral state in 2020 (NEP = −2.13 g C m^{-2} $year^{-1}$) and back to a net carbon sink (NEP = 136.18 ± 49.96 g C m^{-2} $year^{-1}$). The average NEP over the 8-year period was 169.68 ± 41.99 g C m^{-2} $year^{-1}$. The warmest autumn over 19 years recorded in 2020 resulted in noticeably increased ecosystem respiration, which shifted annual NEP towards negative net values, while no significant impact on GEP was found. Our results underscore the importance of continuous monitoring carbon dynamics variability to determine the ecosystem's resilience to seasonal temperature fluctuations and to inform management strategies for mature forests preservation.

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Assessment of multiple mid-infrared absorption (MIRA) analyzers' performance for methane and ethane in the laboratory

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Theme

1. Isotopes and other tracers for studies of methane sources and sinks

Abstract Text

Methane (CH_4) is regarded as an efficient target for rapid mitigation of climate change forcing. Ethane (C_2H_6) to methane mixing ratios can be applied to identify and separate methane sources, specifically in areas with mixed methane sources (e.g. natural gas and biogenic emissions). Aeris Technologies' MIRA Ultra Leak Detection System (LDS) with continuous in-situ measurements for C_2H_6 and CH_4 has been shown (Commane et al., 2023) to have promising measurement performance and modest size and power requirements. In this study, we tested instrument response to environmental conditions and calibrations in the laboratory to assess three MIRA Ultra gas analyzers' performance for methane and ethane field measurements. Anticipating use in tower-based deployments requiring high compatibility, we used an external pump in place of the internal pump, dried the air sample, and humidified the calibration gas. We compared results with those of a co-located Picarro G2301. We will describe the precision, bias and drifts found among the instruments, and strategies for controlling instrument performance in the field.

Reference:

Commane, R., Hallward-Driemeier, A., and Murray, L. T.: Intercomparison of commercial analyzers for atmospheric ethane and methane observations, Atmos. Meas. Tech., 16, 1431–1441, https://doi.org/10.5194/amt-16-1431-2023, 2023.

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Deciphering Arctic Ocean surface ocean carbon fluxes: Insights from Atmospheric Inverse Analyses

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

The Arctic Ocean contributes significantly to the uptake of oceanic CO_2, despite covering only a small fraction (about 4%) of the Earth's ocean surface (Bates & Mathis, 2009). This study examines the exchange of CO2 between the atmosphere and the Arctic Ocean. We utilize the GEOSChem-LETKF inverse model system (Chen et al., 2021) in conjunction with alternative representations of air-sea CO_2 fluxes (prior fluxes) and with atmospheric measurements from the NOAA surface CO_2 monitoring network (ObsPack, Cooperative Global Atmospheric Data Integration Project, 2018) to derive optimized surface flux estimates. We assess the sensitivity of our derived flux estimates for ocean and land to different representations of the prior flux distribution and to configuration of the atmospheric observational network. We also present estimates of the long-term trend, year-to-year variations, and regional and seasonal fluctuations in air-sea CO_2 exchange in the Arctic Ocean focusing particularly on the area north of 58˚ latitude.

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Spatial distribution and isotopic signature of methane emissions over the Spanish rural area of the Gredos mountain range.

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Theme

1. Isotopes and other tracers for studies of methane sources and sinks

Abstract Text

Greenhouse gases emissions must be reported to the United Nations Framework Convention on Climate Change. The need to characterize the origin of different methane (CH_4) sources has led to the widespread application, by the international scientific community, of the isotopic measurement of $\delta^{13}C$ which allows analyzing the possible contribution of the different sources to the atmospheric methane. Measuring the ratio of the stable isotopes ^{13}C and ^{12}C, and its variability, allows to differentiate if the methane emissions have occurred from livestock, bodies of water, industries, and other natural or anthropogenic sources.

In November 2015, intensive large-scale campaigns of atmospheric CH_4 concentrations were carried out in the rural area of Gredos and Iruelas (Central Spain) using a Cavity Ring-Down Spectroscopy (CRDS, Picarro G2301) instrument mounted on a car. The work was realized within the framework of the project 'Methane Interchange over the Iberian Peninsula' led by the Catalan Institute of Climate Science (Spain). During these transects air flasks samples were also collected at 6 different points and then analyzed at the Laboratoire des Sciences du Climat et l'Environnement (France) using a G2201-i Picarro instrument to perform an isotopic characterization of the measured methane. Atmospheric CH_4 concentrations were also continuously measured at two fixed sites during the campaigns.

Results of the spatial distribution and of the isotopic signature of the local methane emissions will be presented and discussed here.

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Understanding and modelling the response of high latitude ecosystems to extreme meteorological events with the ORCHIDEE land surface model

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

With the ongoing climate change, high northern latitudes are experiencing an increasing frequency of extreme meteorological events, such as heat waves, snow-rich years, extreme precipitation or, conversely, droughts. Such events can drastically disrupt soil and vegetation dynamics, especially in permafrost environments, which are sensitive to temperature and soil water content. To study this sensitivity, we will analyse several sites, including certain ICOS sites known for enduring such extreme events. The first step is to study the meteorological time series and to infer the event's amplitude by analysing the anomalies compared to the climatology of the site. To this end, local meteorological measurements are exploited to account for the site-specific characteristics in parallel with reanalyses to extend the data series. A second part then focuses on analysing the ecosystem response to each extreme event. That includes soil temperature and water content, LAI and greenhouse gas fluxes. Finally, we will check the ability of the land surface model ORCHIDEE to represent the impacts of each extreme event on the biosphere by forcing the model with the observed meteorological variables and by comparing the simulated results with the observations.

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Preferential combustion of ethane during incomplete combustion of natural gas leads to underestimation of thermogenic methane contribution

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Theme

1. Isotopes and other tracers for studies of methane sources and sinks

Abstract Text

The fraction of natural gas in mixed methane (CH_4) source areas is often quantified by comparing the observed atmospheric ethane (C_2H_6):CH_4 ratio to that reported in the pipeline. However, this approach assumes no change in the C_2H_6:CH_4 ratio during the natural gas combustion process. We observed depleted ethane (lower C_2H_6:CH_4 ratios) in combustion plumes with high carbon monoxide (CO) at a rooftop observatory in New York City (Jan-June over multiple years). In order to determine the source of the incomplete combustion, we sampled the stack exhaust from a natural gas boiler and found badly operated boilers can release CH_4, C_2H_6 and CO during the incomplete combustion of natural gas, but with C_2H_6 depleted relative to the C_2H_6:CH_4 ratio of the incoming pipeline. Previous studies using ethane:methane would have underestimated the natural gas contribution of methane emission if they assumed an unchanged C_2H_6:CH_4 ratio.

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Addressing forest canopy decoupling in eddy covariance flux measurement networks

Georg Jocher[1,2], Natalia Kowalska[1], Heping Liu[3], Sonia Wharton[4], Leonardo Montagnani[5], Dario Papale[6]

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

The eddy covariance (EC) method is the standard technique for determining forest ecosystem-atmosphere turbulent exchange, however, it encounters a significant challenge: the air masses below the canopy often become decoupled from the air masses above it. Consequently, the EC measurements of scalar fluxes (e.g. H_2O and particularly CO_2) above the canopy can be biased due to missing signals from below-canopy processes.

Multiple approaches have been developed in the recent decades to address decoupling (e.g. u_* filtering, quality flags, storage change evaluations, advection measurements), however, all of them appeared to be insufficient to fully tackle the problem. A promising additional approach is based on subsequent EC measurements below and above the canopy.

To date, there is no standardized approach to address decoupling yet. A specialized working group within ICOS strives for addressing this by conducting an extensive multi-site experiment. This multi-site experiment aims to

i) evaluate the performance of different types of sonic anemometers below canopy for decoupling investigations,

ii) explore the spatial heterogeneity of below canopy processes in relation to decoupling,

iii) develop a robust procedure to integrate decoupling investigations in the standard processing of EC measurement networks.

The anticipated experimental design involves three testing sites, namely a deciduous broadleaf forest in flat terrain (Lanžhot, Czech Republic), a coniferous forest in mountainous terrain (Renon, Italy), and a tall evergreen needleleaf forest in moderately complex mountain-valley terrain (Wind River, USA).

This presentation will set the proposed experiment on a solid theoretical background, introduce the measurement design and discuss the experiment aims.

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Simulated Detection of Methane Emissions from Arctic Permafrost Thawing Contribution with Atmospheric Radiocarbon and Other Tracer Measurements

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Theme

1. Isotopes and other tracers for studies of methane sources and sinks

Abstract Text

Permafrost underlies about 25% of the land in the northern hemisphere and contains over half of global soil carbon. Notably, the Arctic temperature is rising four times faster than the global average. The rising temperature due to global warming induces microbial decomposition of frozen organic carbon, leading to significant soil carbon loss through the release of carbon dioxide and methane. Although various studies have shown concerns towards methane released from thawing permafrost, the scope of its influence and precise contribution to global atmospheric methane levels remains uncertain. Recent atmospheric CH_4 data have indicated that Arctic CH_4 emissions have increased in summer and autumn; however, the attribution to permafrost carbon vs recently fixed carbon or fossil fuels is still lacking. Here we present simulations for Arctic sites in Alaska and Siberia of radiocarbon (^{14}C) and stable isotopes (^{13}C, D) in atmospheric CH_4 as well as atmospheric ethane to show how these observations could attribute regional CH_4 emissions to permafrost carbon vs other sources. We consider differences in the age of permafrost carbon in different regions that determine the depletion of ^{14}C due to radioactive decay in permafrost carbon. Our results are important to assessing regional-scale Arctic CH_4 sources and potential climate change tipping points, and they will be used to inform the planning of future atmospheric measurements.

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Inversion of anthropogenic and biospheric CO_2 fluxes in the city of Zurich from a network of mid-cost CO_2 sensors

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Inverse modelling has become an important tool supporting climate change mitigation as it allows estimating greenhouse gas emissions from atmospheric observations. Since July 2022, a dense CO_2 sensor network with 208 low- and 27 mid-cost sensors has been operating in the city of Zurich in the framework of the ICOS-Cities PAUL project. Together with measurements at three background sites, these sensors provide detailed information on the spatial gradients and temporal variability of CO_2 within the city and between the city and its surroundings. We estimate anthropogenic and biospheric CO_2 fluxes from these observations using the ICON-ART atmospheric transport model in combination with the ensemble Kalman smoother inversion framework CTDAS. For the results presented here, we only assimilated observations from the background sites and the mid-cost sensors installed on rooftops (14 locations), as they are least influenced by local sources that cannot be resolved by the ICON-ART model. The ICON-ART simulations of meteorology and CO_2 were performed for two coupled domains: Europe at 6.5 km resolution and a 60 km wide domain centered on Zurich at 0.5 km resolution. Differences in observed and modelled concentrations were then linearly mapped to flux changes using the ensemble Kalman smoother approach implemented in CTDAS. We find largest differences between prior and posterior fluxes during the winter 2022-2023 especially during the Christmas holidays which corresponds well to the electricity consumption data in the city.

Acknowledgements: ICOS-Cities/PAUL, has received funding from the European Union's H2020 Programme under grant agreement No. 101037319

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Influence of meteorological conditions on a young beech forest gross primary productivity: Insights from 24 year-long measurements using a novel wavelet-based approach

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Gembloux Agro-Bio Tech - University of Liege, Gembloux, Belgium

Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

Forests, as vital carbon sinks, face mounting challenges due to the increasing frequency of extreme events. These events, particularly heatwaves, storms and droughts, highlight the need of understanding how forests respond to environmental stresses. To tackle this challenge, long-term studies provide a unique lens through which we can unravel the intricate dynamics of forest ecosystems and their relationship with climatic fluctuations. In this context, our research focuses on a 24-year dataset of continuous CO_2 measurements from the recently ICOS-labelled Hesse site, a beech-dominated forest under temperate conditions in north-eastern France. We introduce a novel approach using the continuous wavelet transform, a time-frequency analysis tool, to define indicators of gross primary productivity (GPP) intra-annual dynamics. Our study uncovers critical temporal windows during which current or previous year meteorological conditions significantly impact beech photosynthetic activity and eco-physiological behavior. Notably, precipitations during a 1–2 week period in July-August emerges as a pivotal phase for next year's GPP dynamics. Furthermore, radiation, air temperature, vapor pressure deficit, precipitations and soil water availability exhibit both short and long-term effects on GPP. Our proposed approach disentangles these influences, identifying dominant periods for each variable and their localized impact on GPP dynamics. By unraveling these correlations, our study provides insights supporting a comprehensive understanding of forest resilience and yields critical information for developing sustainable forest management strategies in response to shifting climate patterns.

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UAV Based In-situ Measurements of CO2 and CH4 Emissions

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Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

Heterogeneous landscapes, such as Arctic permafrost regions, induce significant variations in carbon fluxes (CO_2 and CH_4) even on small spatial scales, leading to biases in upscaling the carbon fluxes from eddy-covariance towers and flux chambers due to their limited spatial representativeness. To mitigate these inherent biases, unmanned aerial vehicle (UAV) based measurements may complement the existing carbon monitoring network. However, only a few studies focused on UAV-based greenhouse gas (GHG) measurements.

This study introduces a recently developed UAV platform equipped with two portable gas analyzers to measure the concentrations of CO_2 and CH4, along with an anemometer to measure 2D wind speed, air temperature, humidity, and pressure. The UAV platform was tested within the sub-Arctic permafrost peatland in Northern Sweden (Stordalen Mire). Grid flights were used to generate concentration maps of GHGs to assess the signal variability and to identify potential hotspots. Additionally, vertical profile flights were conducted to resolve the lowest part of the atmospheric boundary layer. These vertical profile flights were used to quantify the GHG fluxes and the comparison was made using the ICOS eddy-covariance tower within Stordalen Mire. Although subjected to large uncertainties over the area of interest, the comparison between the eddy-covariance method and UAV-based calculations showed acceptable qualitative agreement.

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Towards a multi-platform open-ocean observatory

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Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

The Porcupine Abyssal Plain sustained observatory (PAP-SO) is an ICOS-labelled fixed ocean station and part of the OceanSITES network of year-round measurements situated in the Northeast Atlantic (49°N 16.5°W, 4850 m). PAP-SO is one of the longest running open-ocean multidisciplinary observatory in the oceans around Europe. The site has produced high-resolution datasets integrating environmental and ecologically relevant variables from the surface to the seabed for >20 years. Since 2002, a mooring has been in place with autonomous sensors measuring Essential Ocean Variables (EOVs) in the surface ocean. EOVs include temperature, salinity, dissolved oxygen, chlorophyll-a fluorescence, nitrate and pCO_2 in high temporal resolution. Since 2010, the collaboration between the UK's Meteorological Office and Natural Environment Research Council delivers simultaneous, open-access atmospheric and surface ocean datasets in near real-time.

Observatory research is increasingly focused on the causes and consequences of multidecadal change and on monitoring EOVs. To do this the infrastructure is being advanced steadily (e.g. moving towards pCO_2 sensors with reference gas measurements) as is the use of different platforms (e.g. deploying BGC-ARGO floats and gliders) helping to improve data quality control of moored sensors. The site attracts process studies and novel technology trials alongside established techniques as part of (inter)nationally funded collaborations and demonstrator missions due to the extensive in-situ measurements available. Here we present ongoing future technology developments that will advance the transition of PAP-SO to a cost-effective multi-platform observatory for sustained carbon observations.

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Modelling carbon recovery time after clear-cutting or fire in boreal forests under changing climate

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

The boreal forest covers approximately 12 million km² and contains one-third of the terrestrial vegetation carbon, making it a vital component of the global carbon cycle. The impact of forest harvesting (e.g. clear-cuts) and forest fires on forest carbon budgets under climate change is still not well understood. This study presents results from simulations with the process-based dynamic global vegetation model LPJ-GUESS conducted for the boreal forests of Sweden, specifically at Norunda (ICOS) and at a forest in the Ljusdal area (central Sweden). At Norunda, we simulated the clear-cut of a 120-year-old mixed pine-spruce forest and a subsequent set of reforestation approaches. In Ljusdal, where forests were severely affected by wildfire in 2018, we conducted simulations of the forest fire and several post-fire management options with LPJ-GUESS and the fire module SIMFIRE-BLAZE. The model outputs were validated against in-situ observational data (eddy-covariance carbon fluxes, forest characteristics) from the forest stands. Both studies included simulations until the year 2100 following two distinct climate scenarios. We estimated the carbon recovery time using the carbon compensation point (CCP) following clear-cut or forest fire. We found that the CCP for different types of reforestation approaches at Norunda ranged from 12-16 years. For the Ljusdal forest, CPP was reached only 18-33 years following the forest fire and subsequent reforestation strategies, mostly due to carbon-dioxide emissions during the fire. These findings could guide the adoption of suitable reforestation strategies after clear-cutting or wildfires to maximize carbon recovery in boreal forests.

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To what extent does CO2 diurnal cycle impact carbon flux estimates in CarboScope?

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Our study focuses on quantifying the impact of the CO_2 diurnal cycle on the annual carbon fluxes estimated with the CarboScope (CS) atmospheric inversion at regional, continental, and global scales for the period of time 2010–2020. Biogenic fluxes of hourly Net Ecosystem Exchange (NEE) obtained from the data-driven FLUXCOM estimates are used in the inversion together with global and regional atmospheric transport models. Results demonstrate differences between CO_2 mixing ratios simulated with daily averaged and hourly NEE. As a consequence, these differences lead to systematic biases in CO_2 flux estimates when ignoring the diurnal variations of the CO_2 flux in the atmospheric inversions. Although the impact on the global average of estimated annual flux is negligible, significant biases are found in the annual flux budgets at continental and regional scales. For Europe, the annual mean difference in the fluxes arising from the diurnal cycle of CO_2 represents around 48% of the annual posterior fluxes (0.31 Pg C yr^{-1}) estimated with CarboScope-Regional. Furthermore, the differences in NEE estimates calculated with CS increase the magnitude of the flux budgets for some regions such as northern American temperate and northern Africa by a factor of about 1.5. To the extent that FLUXOM diurnal cycles are realistic at all latitudes and for the station set used in our inversions here, we conclude that ignoring the diurnal variations in the land CO_2flux leads to overestimation of both CO_2 sources in the tropical lands and CO_2 sinks in the temperate zones.

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A dynamic soil, plant, animal and atmosphere modelling system for NH_3 exchange in grazed grasslands

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Theme

2. Exchange of reactive gases and aerosols between the land surface and the atmosphere in natural and managed ecosystems

Abstract Text

The bidirectional exchange of ammonia (NH_3) between the biosphere and the atmosphere in grazed grassland ecosystems is controlled by complex interactions between soil, vegetation, animals, and atmospheric processes. Conceptualized using resistance transfer models, the net NH_3 exchange results from fluxes in plant stomatal and cuticular pathways, soil surface nitrogen (N) dynamics associated with urea hydrolysis, meteorological conditions and environmental variability. The Generation of Ammonia from Grazing model (GAG), developed originally for an extensively managed grassland in the UK, was tested and further adapted to the intensively grazed grassland ICOS flux tower station at FR-Mej (Méjusseaume, NW France). Here, surface-atmosphere flux measurements of NH_3 were carried out using the aerodynamic gradient method, and CO_2, H_2O, N_2O, and CH_4 fluxes were measured by eddy covariance. Supplementary ecological data (soil mineral N, plant canopy height, leaf area index (LAI), above-ground biomass, animal presence, organic and mineral fertilization and high-resolution meteorological and soil physical variables) have been collected since 2020. The initial application of GAG highlighted limitations in accurately predicting grazing-induced NH_3 fluxes. To address this, we introduced dynamic LAI and canopy height seasonality and updated the model equations to enhance the representation of plant (stomatal) resistances and in-canopy transfer, thereby reducing flux biases. Our ongoing work involves refining soil processes (including soil ammonium adsorption) to address the positive post-grazing NH_3 flux biases and conducting sensitivity analysis of the GAG model. Through this, we aim to advance our understanding of NH_3 emissions and their impact on nutrient cycling in grazed grasslands, capturing the complexity of the soil-plant-animal-atmosphere system.

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$^{14}CO_2$-based Fossil Fuel CO_2 Flux Estimation in Zurich Using Relaxed Eddy Accumulation

Ann-Kristin Kunz[1], Lars Borchardt[2], Dominik Brunner[3], Jia Chen[4], Andreas Christen[5], Lionel Constantin[3], Markus Eritt[2], Rainer Hilland[5], Natascha Kljun[6], Richard Kneißl[2], Virgile Legendre[2], Junwei Li[4], Betty Molinier[6], Stavros Stagakis[7], Samuel Hammer[8]

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Cities are hotspots for fossil fuel CO_2 ($ffCO_2$) emissions, but biospheric and human respiration fluxes can be significant sources of uncertainty for independent top-down validation of $ffCO_2$ emissions. While regional atmospheric CO_2 concentration signals can be separated into fossil and non-fossil contributions by $^{14}CO_2$ analyses, direct measurements of $ffCO_2$ fluxes with the eddy covariance (EC) method have so far not been possible due to a lack of fast-response $^{14}CO_2$ gas analyzers. To overcome this limitation, a novel relaxed eddy accumulation (REA) system was developed within the ICOS Cities project that for the first time allows $^{14}CO_2$-based estimation of $ffCO_2$ fluxes over an urban area.

During the ICOS Cities Zurich campaign from July 2022 to April 2023, the inlets of the ICOS REA system were installed on a 16.5 m high mast on top of a 95 m high-rise building near the city center of Zurich, Switzerland. Based on the 20 Hz vertical wind of a co-located EC system (IRGASON, Campbell Scientific), samples were diverted into updraft and downdraft flasks, excluding a deadband. 103 flask pairs were selected for $^{14}CO_2$ analysis based on suitable micro-meteorological conditions. We present the first $^{14}CO_2$-based CO_2 flux partitioning and compare the observed results with estimates from the Zurich emission inventory and from a high-resolution VPRM model considering the specific flux footprints during the sampling intervals. A generally small signal-to-noise ratio of measured $ffCO_2$ concentration differences is the main challenge of this new technique. We therefore discuss measures to increase the $ffCO_2$ flux signals for future campaigns.

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Terrestrial flux products from an extended data-driven scaling framework, FLUXCOM-X

Sophia Walther[1], Jacob A. Nelson[1], Fabian Gans[1], Basil Kraft[1,2], Ulrich Weber[1], Gregory Duveiller[1], Zayd M. Hamdi[1], Weijie Zhang[1], Martin Jung[1]

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Mapping in-situ eddy covariance measurements (EC) of terrestrial carbon and water fluxes to the globe is a key method for diagnosing terrestrial fluxes from a data-driven perspective. We describe the first global products (called X-BASE) from a newly implemented up-scaling framework, FLUXCOM-X. The X-BASE products cover the globe at 0.05° spatial resolution for every hour and include estimates of CO2 net ecosystem exchange (NEE) and gross primary productivity (GPP).

Compared to previous FLUXCOM products, the new X-BASE NEE better reconciles the bottom-up EC-based NEE and estimates from top-down atmospheric inversions (global X-BASE NEE is -5.75±0.33 PgC yr-1). The improvement of global NEE was likely only possible thanks to the international effort to improve the precision and consistency of eddy covariance collection and processing pipelines, as well as to the extension of the measurements to more site-years resulting in a wider coverage of bio-climatic conditions. However, X-BASE NEE shows low inter-annual variability, which is common to state-of-the-art data-driven flux products and remains a scientific challenge.
With 124.7±2.1 PgC yr-1, X-BASE GPP is slightly higher than previous FLUXCOM estimates, mostly in temperate and boreal areas, and temporal patterns agree well with TROPOMI-based SIF.

Many further opportunities for development exist. We will outline how the new FLUXCOM-X framework provides the necessary flexibility to experiment, diagnose, and converge to more accurate global flux estimates. Pathways of exploration include methodological choices in the selection and processing of eddy-covariance and satellite observations, their ingestion into the framework, and the configuration of machine learning methods.

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Carbon Fluxes along the GB Land Ocean continuum

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Theme

7. Carbon Cycling along the Land Ocean Aquatic Continuum

Abstract Text

ICOS is established around a conceptual model of the global carbon (C) cycle consisting of fluxes between the atmosphere and the land surface and ocean. Atmospheric CO_2 accumulates at approximately 5 Gt C yr^{-1} ,with the difference between emissions and accumulation entering the ocean and terrestrial biosphere. The other major flux between land and ocean is much less well understood, although it is clear that it may be changing and that a substantial fraction of land-derived C enters the atmosphere in rivers and estuaries. This uncertainty is substantially caused by the multiple steps in this flux including C losses from soils and underlying geology to rivers and the subsequent transfer of a fraction of this material through the Land Ocean Aquatic Continuum (LOAC; rivers, estuaries, coastal shelf seas and the open ocean). There are very few regions where we have a good understanding of the losses to the atmosphere at the various stage s of this transfer. One such environment is Great Britain (GB), a large temperate island in the Northern Hemisphere with high spatial variation in population intensity, underlying geology, peatlands, agricultural development and forestry located in a shallow coastal shelf sea that links through to the open ocean. Over 2014-2017 multiple field programmes worked on the GB LOAC C Cycle. Here we will describe the breadth of this field programme, present highlights from each sector, and bring the data together to estimate the fate of the C emitted from the GB landscape and the factors which control this.

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The ICOS Ocean Thematic Centre: How we can support you in providing data to estimate the Ocean Carbon Sink

Richard Sanders[1], Tobias Steinhoff[1], Ingunn Skjelvan[1], Socratis Loucaides[2], Ute Schuster[3], Andrew Watson[3], Stephen Jones[4], Nicole Dalton[3]

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Theme

17. Best Practices in the landscape of Research Infrastructures: Cooperation, Co-location and other lessons learned

Abstract Text

The Ocean has taken up approximately 25% of the CO_2 we have emitted to the atmosphere (Anthropogenic Carbon), slowing the rate of climate change.. The future trajectory of this uptake will determine the cost and efficacy of any mitigation and adaptation actions we can take to keep climate change impacts within manageable boundaries. Obtaining accurate and up to date estimates of ocean Carbon uptake is crucial for the production of high-quality information products such as the Global Carbon Project produces annually for the Conference of Parties (COP). We know that Ocean Carbon uptake varies widely in space and time and hence large quantities of high quality information is required to track this uptake with high confidence. In Europe, this is provided by the Ocean component of the Integrated Carbon Observation System (ICOS), which consists of multiple ocean measuring stations. These are on research and merchant vessels and on moorings that measure surface CO_2 concentrations, reporting these data to international databases such as SOCAT. The ICOS Ocean Thematic Centre supports this effort by advocating for its ongoing funding within fora such as the WMO, by providing standards, training and software solutions, by supporting technology innovation and by auditing station operations and data quality (a process known in ICOS as labelling). In this presentation we will give an overview of key activities in each area that we have been undertaken over the last two years and provide an overview of plans for the future.

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Estimating European CH_4 fluxes using the CarboScope Regional atmospheric inversion system

Frank-Thomas Koch[1], Saqr Munassar[2], Christian Roedenbeck[2], Luana Basso[2], Christoph Gerbig[2]

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

With an increasing network of atmospheric stations that produce a continuous data stream, top-down inverse transport modelling of GHGs in a quasi-operational way becomes feasible.

The CarboScope regional inversion system embeds the regional inversion within a global inversion using the two-step approach. The regional CH_4 inversion uses Lagrangian mesoscale transport from STILT, prior fluxes for peatlands, mineral soils, biomass burning, termites, anthropogenic emissions from EDGAR v6.0, and ocean fluxes.

The protocol for the inversion follows a protocol of a methane regional inversion intercomparison project for Europe and was applied for running inversions for the period 2006-2020. The domain covers most of Europe (33 – 73N, 15W – 35E) with a spatial resolution of 0.25 degree for fluxes and 0.5 degree for flux corrections inferred by the inversion.

Results for the posterior methane fluxes and uncertainties for the full period 2006-2020 are presented on annual and monthly temporal scale. The sensitivity of the regional inversion results to the far field contributions derived from global methane inversions will be discussed.

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Towards reconciling terrestrial CO_2 flux estimates from regional and global data-driven up-scaling approaches

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

Combining in-situ measurements of terrestrial CO_2 fluxes with relevant information on environmental conditions from in-situ and satellite observations using machine learning is a key method for mapping terrestrial fluxes to regional or global domains. It offers a scalable complementary perspective to process-based models. In the ABZ, this is particularly valueable because the latter still have large uncertainties in representing the dynamics of vegetation, permafrost, and hydrology, with strong implications given the large soil carbon stocks it holds and the potential to trigger global climate feedbacks.

However, data-driven upscaling is inherently dependent on data quantity, quality, the representativeness of flux data, and the relevance of predictors. Observational conditions, both in-situ and spaceborn, are particularly challenging in the ABZ. Modeling the ABZ can therefore potentially benefit from domain specific data streams, such as additional flux data from chambers and observational proxies such as permafrost status.

We systematically explore data-driven terrestrial CO_2 flux estimates in the ABZ originating from products with both a focus on ABZ (Virkkala et al. 2021,GCB) and the global domain (Nelson* & Walther* et al. 2024,BGS). We aim at understanding the robustness of flux magnitudes and their spatiotemporal dynamics. We further explore how the temporal resolution (ranging from subdaily to monthly) as well as how tailoring predictors and training samples to a specific domain can impact CO_2 fluxes. Our work is a step towards better understanding the performance of global and regional upscaling efforts and quantifying CO_2 exchange in the vulnerable and spatially heterogeneous ABZ.

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Integrating scenario planning and real-time monitoring for urban GHG emissions management

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Origins.earth, Paris, France

Theme

12. Translating Scientific CO2 Emission Research into City Services

Abstract Text

In the pursuit of NetZero targets, effective policy implementation is pivotal in reducing urban greenhouse gas (GHG) emissions. However, a notable disparity often exists between cities' objectives and the resultant policy outcomes, often due to a lack of clear metrics for measuring policy impact. Origins is pioneering a holistic solution that integrates data management as well as a real-time monitoring network for monitoring urban emissions.

Origins started developing a novel **scenario planning tool**, capable of simulating GHG emission trajectories under diverse policy interventions. These interventions span building renovations, heating network implementations, modal shifts in mobility, and energy efficiency measures. Through rigorous simulation, cities can tailor comprehensive climate action plans aligned with their specific objectives and constraints.Our target is to provide a global solution that can go beyond scenario planning by incorporating a robust monitoring framework that enables cities to track the actual outcomes of implemented policies.

While still in the developmental phase, our project has already produced promising preliminary results, including the creation of future emission maps based on scenario projections. Initial observations from Paris showcase the potential of our approach to inform evidence-based urban sustainability strategies.

In conclusion, our project represents a significant advancement in bridging the gap between policy intentions and tangible emissions reductions in urban contexts. By offering cities a comprehensive solution for **scenario planning and monitoring**, we aim to empower them in their journey towards achieving NetZero targets and building resilient, low-carbon communities.

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Comparison of intra-urban energy exchange in vegetated vs metropolitan Mediterranean areas: the case study of the city of Naples

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

The constant growth of population living in urban areas creates new opportunity for Urban Green Areas (UGA) to provide ecosystem services for human wellbeing such as cooling effect and carbon neutrality of cities. In this study we investigated the seasonal intra-city surface energy flux to compare the sensible/latent heat fluxes between building areas and a UGA using simultaneous eddy covariance observations in both locations. Here we show that the UGA cooling capacity and carbon uptake are influenced by water availability: multivariate analysis indicates that solar radiation (Rg) was the primary control factor in latent heat (LE) and CO_2 fluxes followed by the air temperature (Tair) and vapor pressure deficit (VPD). The relative importance of VPD was higher in year characterized by drought conditions. As expected sensible heat was larger at the urban site especially around midday in the summer months and throughout the year during nighttime. Latent heat flux at the UGA was characterized by typical daily and seasonal trends while at the urban site it showed a larger variability with not well defined trend. The larger H fluxes could potentially lead to a local increase in the air temperature (above the building) compared to the UGA characterized by larger LE that could lead to a local cooling effect on air temperature.

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Sustainable use of peatlands for agriculture in the Arctic

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

Peatlands hold immense soil carbon (C) reserves. Since the 1930s, vast expanses of peatlands in northern Norway have been drained and converted to agricultural land. This drainage disrupts the ecosystem's hydrology, favoring peat decomposition and transforming peatlands into substantial sources of greenhouse gases (GHGs). To mitigate GHG emissions while sustaining biomass production, various management practices, including rewetting, are being advocated. However, the effects of these mitigation measures on the peatland GHG balance remain largely unexplored in high latitude regions.

We investigated productivity and GHG balance in response to peatland cultivation under varying fertilization and hydrological treatments. The research site lies within the Pasvik valley, Arctic Norway, where grasses are cultivated. GHG fluxes (CO_2, CH_4, and N_2O) were measured from 10 plots exhibiting five water levels and two fertilization levels at a sub-daily interval utilizing automatic chambers during the 2022 and 2023 growing seasons. Elevated water levels can inhibit net CO_2 emissions, converting the ecosystem from a CO_2 source to a sink. However, high water levels also enhance the CH_4 emissions. Sporadic N_2O emissions were observed to be higher under the more intensive fertilization regime. Further analysis will reveal the overall GHG budget and C balance in response to changes in water level, fertilization and harvesting frequency.

Our results quantify peatland GHG potentials under different management scenarios and hold significant implications for guiding peatland management in a climate-friendly manner in high latitude regions.

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Winter-time methane fluxes in boreal and arctic peatlands

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

In the Boreal and Arctic regions, the winter season extending from September to May, is twice as long as the summer season, during which peatlands can emit methane. While this contribution has been estimated from observations, global scale ecosystem models employed in the last model intercomparison underestimate winter-time methane fluxes. To investigate this likely discrepancy between observations and model estimations, we compared simulated winter-time methane fluxes from the two ecosystem models, LPJ-GUESS and ORCHIDEE with observations from 7 sites obtained between 2005 and 2023. Both models simulate soil methane production, oxidation and transport processes, enabling to determine the conditions that limit simulated total methane soil stocks and surface fluxes i.e., soil moisture, temperature and oxygen content. These variables are changing also owing to the snow that lessens gas exchange rate between the soil and the atmosphere during winter. The influence on the methane surface fluxes of snow accumulation, snow cover length and active layer thickness will also be assessed. Thus, we aim to identify which key processes influence methane emissions during the winter season to enhance model representation of boreal and arctic peatlands ecosystems.

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Correlation between the CO_2 time series of the Izaña atmospheric station and the ESTOC oceanic station.

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

The Izaña atmospheric station located on the island of Tenerife at 2373 m.a.s.l. and the ESTOC Oceanic Station at 60 nautical miles north of the island of Gran Canaria, both integrated in ICOS-Spain, monitor in two different but interconnected domains, inside the global cycling of carbon and other greenhouse gases [1]. Moreover, the two stations are separated by a short distance (~100km), which allows for a global view of climate change in the eastern subtropical region of the North Atlantic.

Izaña is normally located above a temperature inversion layer, generally well established over the island, and below the descending branch of the Hadley cell, which offers excellent conditions for in situ measurements of trace gases and aerosols in free troposphere conditions. Its continuous time series of CO_2 concentrations started in 1984. Meanwhile, ESTOC started its measurement programme of the physical and chemical characteristics of ocean waters in 1994.

The first part of this work presents the time series of each station, showing the trends of the main greenhouse gases and other parameters specific to each domain. Subsequently, a comparison between the trends of both time series is presented in order to have a global perspective of the exchange of CO_2 between the atmosphere and the ocean.

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ICOS-Spain atmospheric stations detected transoceanic transport of emissions from Canadianfires over the North Atlantic

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Theme

13. In situ data for climate and other environmental services and policy support

Abstract Text

The devastating wave of wildfires that affected Canada was international concern due to the enormous negative impact on air quality during the summer months of 2023. High temperatures, drought and prevailing meteorological conditions favoured the simultaneous occurrences of many wildfires throughout the country. The global atmospheric circulation with predominantly easterly winds over this region favoured the long-range transport of particles, allowing them to reach different European countries, including Spain. In addition to containing small particles, the plume contained a high concentration of carbon dioxide (CO_2) and carbon monoxide (CO) produced by the burning of biomass.

The atmospheric stations of ICOS-Spain, Izaña (Canary Islands) and El Arenosillo (south Iberian Peninsula) identified episodes where CO_2 and CO in situ concentrations experienced significant variations with respect to background conditions [1]. In this work, correlations between the variations of CO_2 and CO concentrations are shown for different episodes in both stations. In addition, the calculated back-trajectories are shown confirming the origin of air masses from Canada. This event highlights the importance of understanding the dynamics of atmospheric circulation in order to study the potential negative impacts on a region due to events originating hundreds of kilometres away.

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Towards an increasingly biased view on Arctic change

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

The Russian invasion of Ukraine hampers the ability to adequately describe conditions across the Arctic, thus biasing our view on Arctic change. Our study benchmarks the pan-Arctic representativeness of the largest high-latitude research station network, INTERACT, with or without Russian stations. Multiple of these INTERACT stations include ICOS and FLUXNET flux towers measuring terrestrial carbon exchange dynamics across the pan-Arctic region. Our findings reveal pre-existing biases within the INTERACT network in representing key ecosystem conditions across the Arctic. Notably, INTERACT stations are predominantly situated in slightly warmer, wetter regions with deeper snow cover, and exhibit lower vegetation biomass and soil carbon stocks. Excluding Russian stations from INTERACT significantly increases the biases in all key ecosystem variables, decreasing our ability to describe (and project) Arctic changes accurately. In some cases the biases have the same magnitude as the expected shifts caused by climate change by the end of the century. At a broader scale, the loss of Siberian research stations may be particularly detrimental for the ability to track global responses to climate change such as thawing permafrost, shifts in biodiversity, and carbon dynamics.

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Using satellites in support of methane emission reductions

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

The importance of reducing methane emissions to mitigate climate change in the short term has been recognised at the highest political level. By now over 150 countries have signed up to the Methane Pledge to reduce emissions by 30% by 2030 compared to 2020. At COP28 (2023), the International Methane Emission Observatory (IMEO) launched the Methane Alert Response System (MARS) to detect and identify methane super-emitters using satellite data, notify responsible parties, and work together towards reducing their emissions. TROPOMI methane observations are at the core of the MARS system as TROPOMI is the first satellite instrument providing daily global observations of methane super-emitters.

We developed a machine learning approach to detect super-emitters in the TROPOMI data. These detections are used to tip-and-cue high spatial resolution satellites (e.g., GHGSat, Sentinel-2) to identify the exact sources. This way, we were able to identify super-emitting landfills, oil/gas facilities, and coal mines. We will show how this synergistic use of multiple satellites can be used to inform the operators, allowing – for example – gas leaks to be fixed and how the resulting emission estimates can be used to evaluate reported emissions.

We will also introduce the ESA MEDUSA project where we will compare the various satellite products on methane ‘point’ sources, provide a framework for methane flux uncertainty, and where possible validate these through controlled releases. In addition, we will perform a few case studies highlighting the potential of these point source/hot spot methane observations.

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Methane emissions over major fossil fuel basins from bottom-up inventories and atmospheric inversions

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Fossil fuel production is a dominant contributor to the total anthropogenic methane emissions. However, there are large uncertainties in emissions estimates, especially for the oil and gas sector. We analyzed mean annual methane emissions during 2019-2021 for major fossil fuel basins to gauge the range in estimates reported across different datasets. The analysis included 14 basins contributing ~20% to global fossil methane emissions. Three coal basins – Shanxi (China), South Africa and Bowen-Surat (Australia); Ten oil and gas basins – two in North America (Permian, Anadarko), Algeria, Iraq, two in Iran, Kuwait, two in Turkmenistan and Uzbekistan; and One mixed-fuel basin in North America (Appalachian). Emissions are compared across a) regional inversions using bias-corrected methane column mixing ratios derived from TROPOMI on board the Sentinel 5P satellite, b) global bottom-up inventories – CEDS, EDGAR, GAINS, GFEIv2 and c) two ensembles of global inversions based on EDGAR and GAINS as priors respectively. Overall, both bottom-up inventories and global inversions underreport emissions over the basins compared to regional inversions. For all basins combined, the underreporting lies between -34% to -3%, while at the basin level, it can go as high as -96%. Further, regional inversions show a lower spread in estimates per basin than bottom-up inventories and global inversions. This reflects the influence of different data-sources for emissions factors across bottom-up inventories and influence of different inversion systems and combination of priors across global inversions. These findings contribute to improving the consensus among datasets for a better evaluation of global mitigation efforts.

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Evaluation of selected Sentinel-2 remotely sensed vegetation indices and MODIS GPP in representing productivity in semi-arid South African ecosystems.

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

Large scale spatiotemporal assessments of production trends in semi-arid ecosystems rely on satellite data estimates, which often lack well-coordinated ground-based validation datasets, leading to biases. We used GPP estimates from the partitioning of net ecosystem measurements (net ecosystem exchange) from three ground-based Eddy Covariance (EC) flux tower sites and applied linear regressions to evaluate the ability of Sentinel-2 vegetation indices (VIs) retrieved from Google Earth Engine to estimate GPP in semi-arid ecosystems. The Sentinel-2 normalized difference vegetation index (NDVI), enhanced vegetation index (EVI) and the land surface water index (LSWI) were each assessed separately, and also in combination with selected meteorological variables (incoming radiation, soil water content, air temperature, vapor pressure deficit) using a bi-directional stepwise linear regression to test whether this can improve GPP estimates. The performance of the MOD17AH2 8-day GPP product was also tested. While all VIs tracked the phase and amplitude patterns of ground-based GPP across the sites, they notably improved with the addition of meteorological variables. The least improvement in R^2 was observed in all EVI-based estimates – indicating the suitability of EVI as a single VI to estimate GPP. Our results suggests that while a single VI is more advantageous for production assessments, incorporating meteorological variables can enhance the accuracy of single VI estimates in detecting and characterising changes in GPP. In addition, we found that standard MODIS products better represent the phase than amplitude of production in semi-arid ecosystems – underestimating by almost 50% and explaining between 68-83% of GPP variability.

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The LOng-LIved greenhouse gas PrOducts Performances (LOLIPOP) CCI+ project

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

To fully understand the Earth's climate, the impact of greenhouse gases (GHG) should be considered. High-quality datasets of their concentrations, measured by satellite instruments, are essential for this scope. Within the ESA Climate Change Initiative (CCI) program, atmospheric GHGs like ozone, water vapor, carbon dioxide and methane, have already been addressed. Nitrous oxide (N_2O), sulfur hexafluoride (SF_6), carbon tetrachloride (CCl_4) as well as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs), also known as the 'Other long-lived greenhouse gases' (OLLGHGs), are recognized as one of the GCOS Essential Climate Variables (ECVs). and their role as ozone-depleting substances and GHGs is widely known. However, GCOS includes user requirements for N_2O only.

The LOng-LIved greenhouse gas PrOducts Performances (LOLIPOP) CCI+ project aims to fill this gap. The goals of LOLIPOP are:

- assess the state-of-the-art of OLLGHGs satellite measurements,
- provide user requirements for all the OLLGHGs, and compare them with the quality of the existing satellite observations,
- investigate the quality of the existing satellite data with respect to selected applications in climate and atmospheric chemistry models and services.

The final goal of the project is to determine if the quality of the actual set of satellite measurements is good enough for their use in climate science and services. In this case, the construction of a harmonized and consistent dataset of satellite measurements can go ahead.

We will present the work performed in the first part of the project, started in November 2023.

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Expanded Freshwater and Terrestrial Environmental Observation Network: A Landscape Scale Environmental Research Infrastructure in South Africa

Gregor Feig[1,2], Kathleen Smart[3], Warren Joubert[4], Helga Knoetze[5], Amukelani Maluleke[6], Sylvester Selala[4], Jeremy Moonsamy[3], Sachin Doarsamy[3], Nolusindiso Ndara[1], Isaac Gura[1], Marc Pienaar[1], Abri De Buys[4]

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Theme

17. Best Practices in the landscape of Research Infrastructures: Cooperation, Co-location and other lessons learned

Abstract Text

The Expanded Freshwater and Terrestrial Environmental Observation Network (EFTEON) is a research infrastructure that is being developed to support studies on coupled ecological and social systems in South Africa. The design is based on developing six distributed “landscapes”, each representing an important South African Ecosystem/Human complex. Each of the landscapes will have a standard set of automated instruments measuring the carbon and water cycles, meteorology, and air quality. A suite of standard repeated manual measurements covering biodiversity, productivity, ecosystem condition, ecosystem service provision and- use is being implemented. A larger set of subsidiary sites within each landscape, will have simpler standard automated instruments for climate and freshwater monitoring, as well as repeated manual measurements including socio-ecological survey data collection in surrounding communities. These landscapes cover the suite of biomes occurring in South Africa, including arid shrubland, tropical savanna, tropical grassland, high altitude mesic grassland, Afromontane forests, and fynbos, with a range of land use types and tenure systems being represented. This presentation will focus on infrastructure design and developments, and present some preliminary results highlighting activities in the RI, lessons learned and future priorities.

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Lower-cost eddy covariance setups for increasing the spatial replication of CO_2 and H_2O flux measurements above agroforestry

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Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

Conventional eddy covariance (CON-EC) studies typically lack spatial replication due to high instrumental costs. Lower-cost eddy covariance (LC-EC) setups, including slow response sensors for CO_2 and H_2O, might provide a potential solution to the spatial replication problem, despite the flux uncertainty mainly related to their larger high frequency response correction.

In this work, we present (i) a validation of three LC-EC setups for CO_2 and latent heat (LE) flux measurements against a CON-EC setup above a monocropping site and one LC-EC setup above an adjacent agroforestry site; and (ii) results from a distributed tower network equipped with the same three LC-EC setups at the agroforestry system.

Results from the CON-EC and LC-EC comparison indicated a very good agreement of CO_2 and LE fluxes with slopes of the linear regression models between of around 1.0 (R^2=0.9) for CO_2 and between 0.78 and 1.0 (R^2=0.8) for LE fluxes. All setups detected (i) the ecosystem dynamics of CO_2 and LE fluxes and (ii) differences between fluxes from open cropland and agroforestry.

Results of the distributed tower network indicated that the spatial variability in CO_2 and LE fluxes was caused by differences in each tower's footprints, due to changing wind directions, different fractions of crops seen by the towers, variability in phenology of the crops, and management activities. The information gained by the multiple-tower system counteracted the larger uncertainty associated to the LC-EC setups. These results support the use of LC-EC as a tool to study flux heterogeneity in complex land ecosystems.

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Temporal trends in high-resolution flux of Nitrogen-Dioxide (NO_2) from a grazed African Savanna

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Theme

2. Exchange of reactive gases and aerosols between the land surface and the atmosphere in natural and managed ecosystems

Abstract Text

South Africa is a major source for anthropogenic atmospheric NO_2. Emissions from coal power generation and industrialized processes clustered together in the Mpumalanga Highveld form a well-known hotspot of elevated NO_2 concentrations that influence air quality across the southern African region. Natural sources that contribute to NO_2, such as soil emissions and biomass burning, are influenced by climate, geography and human activity. Whilst processes that remove atmospheric NO_2, in the form of wet and dry deposition are associated with rainfall and landscape surface dynamics. The net result of these, imply differences in the seasonal flux for NO_2. Here we perform the first-ever high-resolution measurements of NO_2 exchanged between the atmosphere and a grazed African savannah landscape from 2015-2020. We use micrometeorological eddy covariance techniques with a quantum cascade laser (QCL) instrument to quantify the NO_2 flux and explore temporal trends at diurnal, monthly, annual and interannual scales. Initial findings highlight the variation in NO_2 flux with notable interannual change observed at monthly and hourly scale. Seasonal variation in NO_2 flux is strongly linked to the onset of the rainfall season. Diurnal trends indicate maximum NO_2 flux during daylight hours, with consistently low flux during night-time. These findings contribute to our understanding of near-surface atmospheric NO_2 dynamics in arid landscapes and highlights the importance of shedding light on African atmospheric pollution.

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Verification of an earth system model CCAM using the ground-based measurements across South Africa.

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Earth System models (ESMs) are global climate models with the capability to explicitly represent biogeochemical processes that interact with the physical climate and so alter its response to forcing such as those associated with human-caused emissions of greenhouse gases. Several ESMs exist such as Conformal cubic atmospheric model (CCAM), Community Atmosphere Biosphere Land Exchange (CABLE), Inline ocean model in CCAM and GCI Ocean model (WPOM-Wits Planetary Ocean Model). The limited verification of these models in Africa is a cause for concern and may result in the development of significant biases in the representation of the modelled processes. This study presents the verification of CCAM using ground-based measurements collected in different South African biomes. CCAM is a variable-resolution global atmospheric model that employs semi-implicit, semi-Langrangian methods to solve hydrostatic primitive equations. Data to verify the model representation of significant exchanges between the land surface and atmosphere, including the carbon, energy and water fluxes was obtained from six different EFTEON flux tower sites in South Africa representing a range of Biomes and environmental settings for the period 2020 – 2023. Using the selected variables, the model will be run hourly for the period of 4 years. The successful verification of ESMs would enable the confident use of them in combination with the in-situ observations to identify hotspots of land-atmosphere fluxes and improve the development of the model processes and representations. This study forms part of the KADI project and will inform the development of climate services provision on the African continent.

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Review of existing research infrastructures and design of a concept for pan African research infrastructure

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Theme

13. In situ data for climate and other environmental services and policy support

Abstract Text

Long-term research is critical to address the national research questions which cannot be tackled in the framework of single and time limited projects. Research infrastructures (RIs) enable the understanding of the drivers and patterns of environmental change through long term, collaboration and multidisciplinary research. However, Africa has a limited number and sparse distribution of RIs; in particular for observations of carbon exchange, atmospheric composition, biodiversity, marine processes and human health and population demographics. This thus hinders the development of a comprehensive environmental observation system in Africa. As part of solving or mitigating this issue, the KADI project aims to improve the knowledge about climate change in Africa and develop tools to combat its negative impacts. The current study therefore forms part of this larger project and presents a design of a concept for a pan-African climate observation RI. EFTEON is one of the South African RIs hosted by SAEON that aims to provide knowledge on environmental processes and change including data for biogeochemistry, biodiversity, meteorology and hydrology research. However, similar RIs are needed across Africa. Data from RIs is crucial as it will aid to make informed decisions about climate change mitigation or adaptation measures.

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Seasonal dynamics and temperature sensitivity (Q_{10}) of soil respiration in Afromontane grasslands, Drakensberg, South Africa

Lindokuhle Xolani DLAMINI

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Soil respiration (R_s), a crucial biogeochemical process, is a major pathway for CO_2 emission from ecosystems. Due to its temperature dependence, R_s may increase with global warming, especially in mountainous regions. Afromontane grasslands in temperate high-rainfall regions of South Africa are huge reservoirs of soil organic carbon (SOC). **These ecosystems evolved with fire, and fire-exclusion leads to native plant afforestation. This study investigated seasonal dynamics and Q_{10} of R_s to understand the impact of fire-exclusion-driven afforestation and aspect on SOC dynamics. Using the Cathedral Peak Research Catchments initiated in the 1940s, this study compared** an afforested fire-excluded site to a periodically burnt grassland within the same south-facing catchment. Additionally, it compared the south-facing periodically burnt grassland to a north-facing biennially burnt grassland. Measurements were performed using an 8-chamber **LI-8100A** automated system (north-facing) and a monthly static chamber-based manual technique (all sites, approximately 3 years). **Linear Mixed-Effects Models showed that these two methods were complementary and seasonal variability in R_s was higher during summer than in winter in all sites. This seasonal variability of R_s was influenced by fire, soil temperature, and moisture. The afforested site had less topsoil SOC stocks, more overall $R_{s,}$ and double the Q_{10} compared to the periodically burnt grassland. While fire increased R_s in the first growing season, the cooler south-facing grassland still had lower R_s and Q_{10} compared to both the afforested site and the north-facing slope. While often neglected, this study suggests that aspect play a crucial role in biogeochemical cycling and Afromontane grassland shows greater potential for C sequestration than afforested systems.**

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Insights into hyperparameter-optimisation for shallow artificial neural network used in Eddy Covariance CO_2 flux data gap-filling

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Theme

13. In situ data for climate and other environmental services and policy support

Abstract Text

Many popular Eddy Covariance (EC) CO_2 flux gap-filling methods can work well for the less disturbed ecosystems; however, their application can be challenging for some disturbed ecosystems [1], such as rehabilitated former cutaway-peatlands, which can have very heterogenous nature, represented by vegetation, bare peat and open water areas. Artificial neural networks (ANNs) are one of the well-known machine-learning approaches used for such tasks [1]. This study provides insights into hyperparameter-optimisation for shallow ANN applied via 'neuralnet' function in R [2], used to gap-fill the missing EC CO_2 flux data. Shallow ANNs differ from deep ANNs as they have simpler structure and are thought to be less computationally costly. The study is using an ANN example from Premrov et al (2024)[3], which previously showed promising results in gap-filling the EC CO_2 flux data from Cavemount Bog, a rehabilitated former Irish cutaway-peatland [3,4]. Presented will be insights, such as procedures used to find the optimal hidden-configuration, and the optimal threshold-value for the error-function partial derivatives assigned in the 'neuralnet' [2]. It is thought that these insights may be potentially useful to those who may wish to further investigate this method for similar gap-filling tasks.

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Innovations in autonomous sensor and sampler technologies for ocean carbon measurements through the EU GEORGE project

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Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

The EU project GEORGE addresses the capability gap in ERIC's infrastructure to collect fit-for-purpose in situ measurements of carbonate system parameters including pH, TA, DIC and pCO2, to better characterise and understand inorganic carbon cycling in the ocean, its exchange with the atmosphere and monitor the rate of ocean acidification. A major focus of GEORGE is to advance the TRL (from 6 to 8-9) of novel sensors to enable integration with ERIC infrastructure including fixed platforms and small autonomous platforms such as profiling floats and gliders. Sensor technologies include Lab-on-Chip (LoC) sensors for in situ measurements of pH, Dissolved Inorganic Carbon and Total Alkalinity and infrared based technologies for ocean-atmosphere CO_2 flux measurements. Significant effort is also focused on improving and optimizing commercial off the shelf sensors for integration on fast-moving platforms and enhancing long term measurement performance. Sensor measurement validation technologies including autonomous samplers, calibration systems and anti-fouling strategies are also being developed to ensure data quality over long unattended deployments at sea. This talk will provide an overview of these new developments including their capabilities and plans for their validation and testing.

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Carbon dioxide, methane and carbon monoxide were observed over one-year at the tall tower of El Arenosillo station in Southwestern Europe

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Theme

2. Exchange of reactive gases and aerosols between the land surface and the atmosphere in natural and managed ecosystems

Abstract Text

Carbon dioxide (CO_2), methane (CH_4), and carbon monoxide (CO) – were sampled at three heights (10 m, 50 m, and 100 m) from December 2021 to December 2022, at the El Arenosillo station. Hourly averages exhibited variability based on altitude, ranging from 418 ± 5 µmol mol^{-1} at 100 m to 422 ± 8 µmol mol^{-1} at 10 m for CO_2. For CH_4, the values fluctuated from 1999 ± 30 nmol mol^{-1} at 100 m to 1986 ± 25 nmol mol^{-1} at 10 m, and ~102 ± 19 nmol mol^{-1} for CO. Monthly cycles indicated a peak in January-February for both CH_4 and CO, with the lowest in June. CO_2 reached its minimum in August. These gases exhibited daily patterns, reaching their maximum between 5:00 and 10:00 UTC, while the minimum at 15:00-18:00 UTC. The daily variations are influenced by atmospheric stability, photochemical activity, and vegetation. Factors such as photosynthesis, plant and soil respiration, strongly modulated the CO_2 gradient. In cold months, the CH_4 gradient (12-27 x 10^{-2} µmol mol^{-1} m^{-1}) is influenced by vertical stability and local emissions while CO exhibits negligible vertical gradients. The gradients of CO_2 and CH_4 presented divergent patterns; the 10-50 m gradient for CO_2 was higher than that from 50-100 m, while in CH_4, it showed the reverse. This behavior could suggest a shallower CO_2 surface layer compared to CH_4. Observations at 100 m identified peaks in CO and CH_4 suggesting a connection to the presence of a forest fire plume and fugitive CH_4 emissions.

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Improving Estimates of Arctic Ocean CO_2 Uptake with a new Machine Learning derived $p(CO_2)$ product for the Arctic Ocean

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

The Arctic Ocean covers only 3 % of the Earth's surface but contributes 5 - 14 % of the global ocean carbon sink. Sparse and unevenly distributed in situ sea surface observations of the partial pressure of carbon dioxide, $p(CO_2)$, hinder our understanding of the magnitude and the controlling mechanisms of this CO_2 sink. To overcome these limitations, we adapt the Self-Organising Map–Feed-Forward Neural network (SOM-FFN) method of Landschützer et al. (2016) to construct a monthly 1° × 1° $p(CO_2)$ product from January 1991 to December 2022. We first divide the Arctic Ocean (herein defined as the region north of 55° N) into five biogeochemical provinces using the SOM, and then derive non-linear relationships between $p(CO_2)$ observations and predictor variables (i.e., biogeochemical drivers) for each province using the FFN method. Our reconstructed Arctic $p(CO_2)$ product is then evaluated against additional $p(CO_2)$ observations, chiefly from SOCATv2023 and from independent timeseries stations.

We then use this new $p(CO_2)$ product to derive estimates of the air-sea CO_2 flux for the Arctic Ocean. In line with previous studies, we find the Arctic Ocean to be a sizeable CO_2 sink, with the greatest sink strength in the marginal ice zone . However, the magnitude and seasonal variability of this sink depends on the treatment of sea ice cover in the flux calculation. Uncertainty in the overall flux magnitude is also caused by the choice of gas transfer coefficient, although this is less significant when assessing the magnitude of the Arctic Ocean carbon sink.

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Overview of the terrestrial ecosystem soil database of ICOS ETC and perspectives

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

The use of eddy covariance (EC) techniques is widely used to measure CO_2 exchanges between the surface and the atmosphere, and is the approach chosen in ICOS to monitor 49 Class 1 and 2 terrestrial ecosystem sites. The EC technique accurately monitors the ecosystem's state and CO_2 fluxes. Together with carbon imports as organic fertiliser, carbon exports as harvest (including animal herbivory), and dissolved carbon leaching and losses or gains of C by erosion, these data allow us to compute the carbon balance of the site. Imports and exports data are monitored in ICOS, but not the C leaching and erosion. In ICOS, the carbon balance of terrestrial sites will also be monitored by measuring the soil carbon stock (over 1 m depth) evolution over time with a planned revisit of 5 to 10 years at each site. In 2024, around half of the ICOS sites have sampled soil, and around 20 sites have been analysed. The ICOS analysis at most sites provides the carbon and nitrogen stock evaluation with its uncertainty and variability with depth. The texture is also measured when not already known at each site. For some sites, historical soil sampling could be used to evaluate a soil stock change, with the additional difficulty that the sampling protocol has changed with time. An overview of the existing database and how it compares to European soil carbon maps is given. One identified limitation in the current soil sampling scheme is the missing information on the soil carbon stability, which is key to understanding the long-term fate of carbon in soils.

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MODELING PEATLAND CO2 AND CH4 EXCHANGE UNDER EXTREME WEATHER EVENTS

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

Extreme weather events can cause anomalies in CO2 and CH4 exchange in wetlands. As seen in long-term measurements, extreme seasons can change plant community distribution and move the wetland ecosystem to a different stable state. To study extreme events in current and future climate, process-based ecosystem models, validated by in-situ observations in ICOS and other sites, are used.

Reanalysis weather data, often used to force the models, describes the weather state interpolated in a grid with a few kilometer resolution using weather stations and climate models. However, this type of forcing data may not show all the extremes in full severity. In addition, ecosystem models have their own limitations of representing plant phenology and carbon exchange. These together limit the capability of modeling to represent CO2 and CH4 fluxes under extreme weather conditions and may introduce bias to annual estimates, especially in the future scenarios as the frequency of extreme weather events is expected to increase in the future due to the climate change.

Here we study how two different reanalysis weather datasets (CERRA and CRU-JRA) portray the observed extreme weather events in over 20 pristine and rewetted wetland sites across Europe. Furthermore, the performance of three ecosystem models (JSBACH-HIMMELI, ORCHIDEE-PEAT and DNDC) is compared to in-situ soil biophysical, carbon dioxide and methane measurements. Our aim is to supplement the current IPCC Emission Factors by defining the variability of emissions in current and future climate conditions. This supports the creation of Tier 3 Emission Factors for wetlands.

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Continuous measurements of O_2:CO_2 flux exchange ratios above a cropland in central Germany

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

The O_2:CO_2 exchange ratio of land-atmosphere fluxes (ER) can be used to identify sources and sinks of CO_2 in land ecosystems. During photosynthesis, the ER at the leaf level is approximately -1 mol mol^{-1}, reflecting the uptake of one mole of CO_2 associated with the release of one mole of O_2. However, the ER at the level of entire ecosystems is largely unknown.

Here we present a unique dataset of one year of continuous O_2 and CO_2 flux measurements at the agricultural FLUXNET site Reinshof (51°29'24.0"N, 9°55'55.2"E) near Göttingen, Germany in 2023. Fluxes were calculated using flux-gradient approaches with air sampled from three inlets situated at 0.5, 1.0 and 3.0 m above ground. Dry mole fractions of O_2 and CO_2 were measured using a modified Oxzilla II differential oxygen analyzer (Sable Systems, USA) and a Li-840 (LiCor Biosciences, USA), respectively.

The results show that O_2 and CO_2 mole fractions and net O_2 and CO_2 fluxes were strongly anticorrelated. The ER shows a distinct diel cycle with less negative values during night but also higher uncertainty as well as an annual cycle, with values around -1.5 mol mol^{-1} under bare soil conditions and -1.1 mol mol^{-1} during the growing season. An influence from anthropogenic emissions was observed during the winter with stable atmospheric stratification when winds originated from the city centre. In conclusion, the ER of a cropland showed considerable diel and seasonal variability offering the opportunity to use O_2 flux measurements as a tracer of the carbon cycle.

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Recent developments in measuring XCO_2, XCH_4, and XCO using COCCON spectrometers and their relatives

Andre Butz[1,2,3], Benedikt Löw[1], Ralph Kleinschek[1], Sanam Vardag[1,2], Vincent Enders[1], Lukas Weis[1], Silke Hoffmann[1], Frank Hase[4], Astrid Müller[5], Matthias Max Frey[5], Isamu Morino[5], Hiroshi Tanimoto[5], Jia Chen[6], Thorsten Warneke[7]

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

Ground-based sun-viewing measurements of the column-average dry-air mole fractions of carbon dioxide (XCO_2), methane (XCH_4) and carbon monoxide (XCO) are collected through the networks TCCON and COCCON to validate the respective satellite observations as well as atmospheric model performance. The portable and versatile COCCON Fourier Transform Spectrometers (FTS) also enable new observation concepts ranging from mobile deployments to explorative setups using scattered instead of direct sunlight.

Here, we showcase recent developments in exploring new applications for the COCCON FTS. We report on the deployment of a mobile FTS on a cargo vessel commuting along the southern coastline of Japan to detect the outflow of hotspot emission sources. Further, we highlight the development of an FTS variant suitable for measuring ground-scattered sunlight. We positioned such a portable instrument side-by-side with the stationary CLARS-FTS (California Laboratory for Atmospheric Remote Sensing-FTS) on a mountain observatory above the Los Angeles basin and demonstrated the performance of our portable setup. Finally, we discuss an upcoming collaborative effort of the German COCCON community to deploy several instruments throughout Germany to detect gradients of XCO_2, XCH_4, and XCO on national, regional, and local scales supporting the national monitoring capacity ITMS (Integrated Greenhouse Gas Monitoring System).

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Science communication: opportunities between Vivaldi and the Museum of Knowledge

Alexander Knohl[1], Franziska Koebsch[1], Anne Klosterhalfen[1], Christian Markwitz[1], Ramona Dölling[2], Karsten Heck[2], Nina-Maria Knohl[2], Sandra Potsch[2], Antonius Adamske[3], Mark Barden[4]

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Theme

15. Science communication and outreach to increase the impact of climate research

Abstract Text

Communicating science to the wider public is not only about presenting scientific results, but also about explaining how research is done through the practices, perspectives and collaborations of researchers. Going beyond traditional science communication channels, for example by using museum exhibitions or music performances, offers exciting opportunities to share scientific work with a wider audience.

Here we present two case studies of science communication activities related to the ICOS ecosystem station Hainich (DE-Hai) in central Germany, which has been measuring CO_2, H_2O and energy exchange over an unmanaged old-growth forest for 25 years.

The special exhibition "Digital Forest" at the University of Göttingen's museum of knowledge Forum Wissen showcased a virtual reality installation that immersed visitors in the Hainich study site. Visitors virtually explored how drought conditions under a changing climate impact the exchange of CO_2 and H_2O, along with tree sap flux and forest structure. The exhibition was embedded in outreach activities with primary and secondary school pupils, workshops, guided tours and public policy debates.

The science concert "Four seasons in (climate) change" was a collaboration between the University of Göttingen, the Göttingen Baroque Orchestra and the Detmold University of Music. In workshops, scientists and composers discussed the latest research on climate change. Inspired by the science, the composers recomposed Vivaldi's Four Seasons to reflect how climate change has altered the seasons expressed in the music.

Both activities were well received by the general public and stimulated intense discussions about climate change and its impact on forest ecosystems.

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High emissions of CO_2 and CH_4 due to active-layer warming in Arctic tundra

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

Climate warming is expected to accelerate decomposition of arctic soil carbon, but controlled experiments as deep as the whole active layer are lacking. We deployed a novel experiment using heating rods inserted to the depth of permafrost in Utqiagvik (previously Barrow), Alaska to warm the whole active layer by roughly 3.5°C and measured the impact on soil-atmosphere fluxes of CO_2 and CH_4. We found that the magnitude of warming predicted to occur this century increased ecosystem respiration by ~30%, a temperature sensitivity (apparent Q10 of 2.8; n=79) much higher than that reported by experiments that warmed only the surface, and higher than the decomposition Q10 of 1.9-2 in most IPCC land models. A controlled shoulder-season warming experiment revealed that rapid melt of snow and ice, events which are becoming more common from rain-on-snow, can result in large emissions of methane that would otherwise be oxidized to CO_2 before emission. Thus, warming promotes greenhouse gas emissions from the deepening active layer and longer talik (thawed layer under a frozen surface) season, portends arctic amplification of climate change.

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A Review of Open Fire GHG Emissions in the Mediterranean Region Across Major Inventories

Rabia Ali Hundal[1,2,3], Saurabh Annadate[1,2,3], Paolo Cristofanelli[3], Michela Maione[2,3], Rita Cesari[4], Alessio Collalti[5,6]

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

The increasing concern about greenhouse gas (GHG) emissions from open fires in the Mediterranean requires a thorough evaluation of the estimate approaches especially for carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and black carbon (BC). We analyzed emissions data from key inventories as CAMS, GFED and EDGAR (2003-2020 period). We found significant differences in emissions between datasets, mostly between GFED and CAMS, which account for both anthropogenic and natural fires, and EDGAR, which focuses only on anthropogenic fires from agriculture and waste burning (AWB).Differences are highlighted by contrasting estimates, with EDGAR's AWB emissions for CO_2 and CH_4 in certain years exceeding GFED' and CAMS' ones. Results show continuous interannual variability with significant emission peaks in 2007, 2012, and 2017 corresponding with strong La Niña events, underlining the impact of climatic variability on wildfire activity. The major contributors to the emissions varied over time, with Italy, Algeria and Greece frequently dominating. Large differences for e.g. Italy, Algeria, and Greece, as well as uncertainties for France and Egypt, highlight the problems of accurately accounting for GHG emissions in these countries. For example, in 2012, GFED recognized 35% of CH_4 emissions for Italy, while for CAMS Algeria was the highest with the same percentage. The difference in the data, particularly in the attribution of emissions to specific countries and the identification of top contributors, highlights the crucial need for consistent techniques based on atmospheric in situ observations to untangle discrepancies in the existing inventories.

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Assimilating Mid-Cost CO_2 Sensor Measurements into WRF-Chem Eulerian and WRF-STILT Lagrangian Inverse Modeling for Quantifying CO_2 Emissions in Paris

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Since the early 2000s, many cities have pledged and implemented policies to achieve net-zero emissions by 2050. While most cities' climate plans have been designed from inventories, new approaches relying on emission estimates from atmospheric observations are now being tested in several metropolitan areas. But to effectively monitor highly heterogeneous urban CO_2 emissions using atmospheric observations, dense networks of CO_2 sensors are needed, possibly with cost-effective sensors that have sufficient accuracy and precision. Here, we designed a mid-cost CO_2 instrument for continuous atmospheric measurements in urban areas, targeting an accuracy of 1 ppm on an hourly basis. Since July 2020, nine mid-cost instruments have been deployed within Paris and its vicinity, remaining operational for over three years, with data coverage varying from 52% to 83% across stations. The data acquisition and calibration procedure have been automated by a newly implemented data processing system. Colocation periods with high-precision instruments show that mid-cost instruments achieve accuracies of 1.0 to 2.4 ppm for hourly afternoon data. We assimilate both mid-cost data and high-precision CO_2 measurements into the WRF-Chem Eulerian and WRF-STILT Lagrangian inverse modeling systems, respectively. Our inversion framework also benefits from the use of an hourly fossil fuel CO_2 emission inventory (Origins.earth) at a spatial resolution of 300 meters. Additionally, it utilizes biogenic fluxes derived from a modified VPRM model that integrates Sentinel-2 data and soil water content. This enables us to conduct a comparative analysis of different measurements and models, and to increase the robustness of quantifying CO_2 emissions in Paris.

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Urban Emission Assessment based on High-Resolution Dispersion Simulations and Bayesian Inversion

Junwei Li[1], Jia Chen[1], Dominik Brunner[2], Dietmar Öttl[3], Maximilian May[4], Sanam N. Vardag[4], Andreas Luther[1], Christopher Claus Holst[5], Haoyue Tang[1]

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

City emission assessment is limited by the underlying model resolution if the model fails to reproduce the emission dispersion within urban terrains. Based on the ICOS Cities project, we established a high-resolution building scale modelling framework for Munich using the computational fluid dynamics (CFD) based model GRAMM-SCI/GRAL-ST-ROG for urban air dispersion simulation. In addition, Bayesian inversion was applied to refine estimates of urban emissions.

We used the GRAMM-SCI model to simulate mesoscale wind fields and take larger area wind situations into account by nesting simulation results at different domains and resolutions. GRAL-ST-ROG model then utilized these mesoscale wind fields to simulate the 10-meter spatial resolution wind field, which considered high-resolution land cover information, namely, topography, 3D building, and a self-developed tree cover dataset. To reduce the high computation demands of CFD, we only simulated 2880 selected wind situations and employ a newly developed Match-to-Observation (MTO) algorithm to match the simulated wind field to the wind observation data at each hour of the year. Doppler wind lidar vertical profile data are also used to validate and improve simulated wind fields. Based on Bayesian inversion framework, we optimize the annual total value and the temporal profile of emission inventories.

The development of the model so far focused on NOx simulations but is starting to be extended to CO_2 simulations as first CO_2 observation data become available in Munich. This study provides more detailed understanding of urban emissions and can help environmental management and policy-making to achieve respective environmental standards.

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An autonomous *in situ* total alkalinity sensor

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Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

Total alkalinity (TA) is one of the four measurable parameters used to characterize the oceanic carbonate system. TA data with higher spatial coverage and temporal frequency will contribute to better measurements, modelling, and understanding of the aquatic carbon cycle, providing insights into problems from global climate change to ecosystem functioning. We present an autonomous sensor capable of providing this type of data via *in situ* TA measurements.

This sensor implements a single-point spectrophotometric titration TA assay and is based on a generic ocean chemical lab-on-chip hardware platform with fully integrated fluidic, optical, and electronic components. The sensor samples seawater, adds in a titrant consisting of acid and pH indicator, degasses the resulting solution, and performs an optical measurement. It can carry multiple calibration materials on board, allowing for routine re-calibration and quality checks in the field. The scientific applications of this sensor require reliable accuracy (~0.1%-0.5%) during deployments lasting months in harsh and varying conditions.

This sensor has been tested and demonstrated both in the lab and in the field. It has been deployed in several environments including a North Sea subsea carbon storage experiment, aquarium-grown and natural coral reefs, a Weddell Sea carbon uptake study, and an autonomous underwater vehicle. The results from lab and sea trials show that the technology is in a strong position and regularly meets the scientific requirements for TA measurements. This presentation will highlight the development and evaluation of the instrument and show field data exemplifying its capabilities.

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An effective machine learning approach for improving the global estimate of the land carbon sink

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Ecosystems provide multiple services worldwide, e.g. storing tremendous amounts of carbon and mitigating global fossil fuel emissions thanks to photosynthesis. Present-day (and future) land carbon sinks are primarily estimated by land surface models (LSMs) which are mechanistic tools that simulate the processes occurring at the interface between the atmosphere and the biosphere. LSMs are therefore critical tools for understanding and predicting the dynamics of the land surface. However, LSMs have become increasingly complex and require heavy expert knowledge and computational tools to run. In this study, we showed that machine learning (black box) models could efficiently reproduce process-based (mechanistic) models. To do so, we trained gradient-boosted tree models (GBT models) with the outputs of TRENDYv12 that were initially generated to estimate the global land carbon sink. Data-driven models could successfully reproduce the long-term trends, the seasonality, and the spatial distribution of the global carbon sink and its components, with an average error (RMSE) of 10%. We then refined the global estimate of the land carbon sink by ranking and upscaling weighted averages of the individual TRENDYv12 model surrogates based on their capacity to reproduce fluxtower data from ICOS and other networks. As GBT models can also serve to make near-real time assessments of the carbon cycle of forests, we also investigated the contrasting impacts of last-year El-Nino on tropical forests: we show that the severe 2023/2024 drought in the Amazon caused the largest reduction of productivity in recent history, while the productivity of Congo Basin rainforests did not decline substantially.

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Methane exchange in the floodplain forest

Natalia Kowalska

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Floodplain forests play an important role in the exchange of methane (CH_4) with the atmosphere. However, due to climate change and anthropogenic activities, main factors driving this exchange, such as ground water table and soil temperature, are constantly changing. The studied floodplain forest in Lanžhot, Czech Republic, represents nowadays relatively dry conditions.

The main aims of our study were to quantify the CH_4 emission on the floodplain forest ecosystem level using the eddy covariance (EC) method, with special emphasis on environmental conditions, turbulence development and footprint, as well as to probe all potential CH_4 sinks and sources within the studied ecosystem for arriving at a complete CH_4 budget. The ecosystem-scale CH_4 fluxes were analysed with regards to the CH_4 emissions of water bodies within the EC footprint. CH_4 fluxes from a stream located within the footprint of the EC tower were measured using floating chambers and bubble traps. Studies were complemented by the analysis of the contribution of trees to the CH_4 exchange. For this purpose, stem chambers measured CH_4 fluxes on hornbeam trees, one of the main tree species at the study site and in Central Europe. Additionally, CH_4 fluxes from the soil were included in the analysis to capture all potential CH_4 sources and sinks within the studied ecosystem.

We initially hypothesized that ecosystem-scale CH_4 exchange will be negligible. Our results showed, however, that the whole ecosystem is a small but constant CH_4 source.

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Tracking methane emissions at the site-scale

Felix Vogel[1], Sebastien Ars[1], Lawson Gillespie[1,2], Timothy Khoo[1,3], Siyar Urya[3], John David Pomeroy[4], Anthony Fabian[1,5], Cassandra Worthy[1], Meghan Flood[1]

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

The Government of Canada has announced ambitious emission reduction targets for methane from the oil and gas sector of -75% and -45% for the waste sector by 2030 compared to 2020 levels. To date policy is solely based on emission reporting through inventories and industry-reporting, however, there is growing recognition that atmospheric observations can add important information to better constrain such estimates. In recent years, the subnational greenhouse gas monitoring team has deployed multiple platforms (vehicle-based, low-cost sensors, floating chamber) at different sites to quantify local methane enhancements, which were used in combination with modelling tools to derive emission estimate for industrial facilities (refineries, landfills, wastewater treatment plants) as well in natural areas (rivers, ponds). We will present results from the different campaigns, discussing how well atmospheric observations agree with existing reporting frameworks and what underlying drivers predict local methane emissions and their changes. We furthermore compare the results of different observational techniques from a yearlong deployment and measurements conducted during 41 controlled release experiments at a landfill site.

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WMO IG^{3}IS Integrated Global Greenhouse Gas Information System

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Theme

13. In situ data for climate and other environmental services and policy support

Abstract Text

The WMO-sponsored Integrated Global Greenhouse Gas Information System (IG^{3}IS) aims to further efforts to integrate activity-based emissions information with atmospheric observations and modelling of greenhouse gasses. Together these provide the best possible estimates of greenhouse gas emissions. A critical component of IG^{3}IS is to establish two-way linkages between scientific practitioners and stakeholders in the policy realm, tailoring the research actions to meet policy needs.

To facilitate these efforts, IG^{3}IS coordinates a variety of initiatives. IG^{3}IS leads the stakeholder engagement component of the recently initiated WMO Global Greenhouse Gas Watch (G^{3}W) effort. We host regular webinars and in-person Stakeholder Summits that bring together greenhouse gas scientists with policymakers and stakeholders. We support establishment of new greenhouse gas observational networks and information systems through local feasibility studies, training events, summer schools and expert advice. We work with other international organisations to achieve scientifically based greenhouse gas system development and stakeholder engagement. An important effort is the establishment of good practice guidelines for greenhouse gas emissions information at the various scales of relevance to both researchers and policymakers. In 2022, IG^{3}IS released the first urban-scale good practice guidelines (WMO GAW Report 275), and are now drafting national-scale and forestry-scale guidelines along with a second edition of the urban-scale guidelines. These guidelines can only be successful with strong community input and we will present current drafts of these documents and ways that the community can get involved.

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Retrievals of CO_2 and CH_4 Maps from the EnMAP Satellite Using RemoTeC and Matched Filter

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

Satellite measurements are an important tool for the global monitoring of anthropogenic greenhouse gas emissions. While it is not a primary mission goal, the Environmental Mapping and Analysis Program (EnMAP) satellite is able to measure carbon dioxide and methane emission plumes from localized hotspot sources. We analyze observations of point and area sources of these gases taken by the EnMAP satellite, including a power plant in Riyadh, Saudi Arabia, an oil and gas facility in Turkmenistan, and the Pinto landfill in Madrid, Spain. We employ a physical retrieval (RemoTeC), which yields integrated column densities for the targeted greenhouse gas, and a statistical retrieval (matched filter), which outputs enhancements only, albeit being much faster and requiring less auxiliary data.

First results indicate that the physical retrieval performs better at distinguishing surface albedo structures from the spectral signal of the target gas for some surfaces. The retrieved image contains a striping pattern caused by detector properties. The matched filter yields a smoother and destriped enhancement map, as it determines detector properties from the measurement statistics. It yields a lower total integrated mass enhancement for the emission plume than the physical retrieval. We aim to improve the retrieval tools, including by using the covariance matrix from the statistical retrieval as input information for the physical retrieval. A first analysis suggests that this combination method results in a smoothed and destriped image without sacrificing the accuracy of the physical retrieval.

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Paris Mid-cost CO_2 sensor network : performance assessment and suitability for city CO_2 emission retrieval.

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

A network of 26 Midcost CO_2 sensors has been deployed at the roof level in the Paris urban and suburban area in the framework of the ICOS-Cities project. The purpose of such dense CO_2 monitoring network is to feed an atmospheric inversion system for the quantification of CO2 emissions at the sub-city scale and/or discern specific sectors.

The presentation mainly deals with the sensor characterization and the appropriate calibration strategy. It focus on corresponding sensor performance in the field. Then it attempts to discuss the pertinence of such monitoring approach and its suitability for the city CO_2 emission quantification.

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Eddy Covariance measurements of CO_2 fluxes at short and tall towers in the Paris area

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Cities are hotspots for greenhouse gas emissions, accounting for over 70% of global CO_2 emissions (IEA, 2008). Accurate quantification of these emissions is crucial for developing and verifying effective mitigation strategies.

Within the ICOS Cities project, eddy covariance measurements of CO_2 fluxes are currently running at two urban sites in Paris as part of a large pilot observatory for GHG emission estimation of the Paris region. The two sites, a short tower on a rooftop in the centre of Paris (Jussieu) and a tall tower on the NE periphery of the city (Romainville), exhibit different land cover composition within their footprint, with urban density decreasing from Jussieu to Romainville.

The analysis of one-year flux measurements (February 2023-January 2024) revealed seasonal variations in monthly diurnal patterns reflecting the interplay of anthropogenic and biogenic CO_2 drivers at the two sites.

During cooler months (October-March), anthropogenic emissions similarly dominated daily exchange patterns at both sites. Conversely, in May and June, only Jussieu displayed predominant CO_2 emission during daylight hours, while Romainville showed traces of biogenic absorption, being closer to the diurnal CO2 flux patterns observed at ICOS ecosystem sites near Paris (FR-FON forest,FR-GRI crop). Throughout summer months (July-August), depopulation substantially decreased anthropogenic sources, resulting in slightly negative CO_2 fluxes during daylight hours, even in Jussieu.

Weekends and weekdays patterns differed in Jussieu, showing an influence of people's habits on diurnal fluxes in the city centre. This was not the case for Romainville, where more uniform flux cycles were observed throughout the week.

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Comparative Analysis of Prediction Models for CO2 Forecasting Across Diverse Ecosystems Using the ICOS Network

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

The increasing trends of CO2 as a greenhouse gas are one of the strong threats to humankind, so that obtaining good forecasts of CO2 evolution is of crucial importance. In this study, a comparison of state-of-the-art prediction models for CO2 time series forecasting is made between over 30 CO2 measurement stations of the Integrated Carbon Observation System (ICOS). These stations correspond to different land covers and vegetation types. Furthermore, the stations are distributed across several climates of the Köppen Geiger climate classification. In the study, performance comparisons are made at each station between statistical, machine learning, deep learning, language models and mixed models. This work proves the usefulness of the data provided by ICOS, not only for studies of past behaviour but also as a solid basis for the development of forecasting models. The study provides model predictions with mean absolute percentage errors (MAPE) of less than 1% for daily observations one year ahead for over 20 stations and an error of less than 2% for all stations studied. Additionally, a comparative analysis of model performance at different measurement heights is carried out for the stations with available measurement heights.

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A Near Real Time Framework for the Detection and Attribution of Carbon Flux Anomalies

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

Integrated greenhouse gas monitoring and verification systems require reliable information on surface-to-atmosphere fluxes of trace gases. In support of the US government's Greenhouse Gas Center (GHG), a workflow has been developed to provide near-real-time (NRT) land surface fluxes of carbon dioxide and methane and their uncertainties, using a cloud-based analysis framework. The flux products are generated via simulations of the LPJ-EOSIM dynamic global vegetation model, which has been used in the land surface ensembles for the Global Carbon and Methane Budgets of the Global Carbon Project for over a decade. Here, we extend the NRT framework to enable the rapid detection and quantification of the response of biospheric methane and carbon dioxide fluxes to extreme climate events on a global and regional scale. We discuss the mechanisms behind some of these regional anomalies and highlight long-term trends in increasing carbon flux anomalies with respect to the long-term mean. Our results demonstrate the need and value for more comprehensive monitoring and verification systems, along with fundamental research into the biospheric feedback loops driving the anomalies.

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Emissions of the oxides of nitrogen (N_2O/HONO/NO) from fertilized soils

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Nitrous oxide (N2O) is one of the mightiest greenhouse gas and HONO and NO play an important role in atmospheric photochemistry. However, the current situation of the emissions of the oxides of nitrogen (N_2O/HONO/NO) is still remain unknown in Taiwan. In this study, field experiments were conducted to examine the emissions of oxides of nitrogen from two major crop types, which were determined by eddy covariance and gradient approaches. Our results revealed that oxides of nitrogen were significantly enhanced after soil fertilization and most of the estimated fluxes exhibited a clear diurnal patterns which were likely to be emitted during daytime, with a maximum value at noon (peak appearing at 11:00 to 12:00) and decreased at night. Seasonal variation in oxides of nitrogen emissions was significant across all treatments. Moreover, compare to upland crop (i.e., cabbages), oxides of nitrogen fluxes were performing a relative lower emissions during the wetland cultivation period, irrespective of N-fertilizer background. This implies that presence of fluxes emissions increased significantly during dry warmer seasons, but can be observed alleviated during cold seasons. Therefore, the impact of N-species emissions from the agricultural soil should focus on understanding the environmental drivers as well as field management (fertilization, irrigation, cropping systems etc.), as it can mitigate significant oxides of nitrogen emissions.

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Five-year continuous measurements of CO_2 and CH_4 at the Atlas Mohammed V Atmospheric Research Station in Morocco.

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

An analysis of the long-term trends and temporal variations of the primary greenhouse gases (CO2, CH4) was conducted at the Atlas Mohammed V atmospheric research station in Northwest Africa. This study employed a complex sample setup and a Cavity Ring Down Spectrometer (Picarro G2301) from the Atlas Mohammed V atmospheric research station in North West Africa (33.4018N; 5.10489E). The measured mean values of CO2 and CH4 are 415.85 ± 0.25 (ppm) and 1947.26 ± 2.18 (ppb) respectively, which is correlated with the global concentration observations. The mean annual growth rates of CH4 (15.73 ± 3.23) ppb and CO2 (2.75 ± 0.24) ppm) closely align with the prevalent worldwide patterns. At the daily scale, the seasonal variation of CO2 does not exhibit any strong trends, except for a slight decrease during the daytime. However, for CH4, a significant increase is observed towards the end of the day. The concentration variations of both gases display significant seasonality, with peaks occurring during the spring and winter for the two gases, and minimum observed throughout the summer period spanning from June to September. Special focus was placed on the data collected during the intense Atlas 2019 campaign in Morocco, where the AMV station played a key role. Deploying an EM27/SUN instrument from September 17 to October 14, 2019, to measure the total column of XCO2, XCH4, and XCO. The data set generated during the Atlas campaign underscores the AMV station's ability to carry out continuous, long-term observations.

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Intense transport of biomass burning products to the tropical Andes as witnessed by a unique station in Southern America

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

The 2023 Amazon fire season witnessed a record number of wildfires, likely exacerbated by the ongoing drought and the positive phase of ENSO. The lack of rain, and the consistently high temperatures, created conditions that allowed wildfires, usually man-made, to spread rapidly across the region. Bolivian Amazonia, covering 11% of the Amazon basin, was severely affected, with 180,000 hectares of forest burned by November. The smoke traveled long distances, affecting the air quality of large regions in the country, including some in the western highlands in the tropical Andes. During this period, the Chacaltaya GAW station (CHC, 16.3ºS, 68.1ºW, 5240 m a.s.l.), the highest in the world of this type, conducted measurements of atmospheric concentrations of greenhouse gases (CO2, CH4), reactive gases (CO, O3, SO2), and aerosols (eBC). This station, strategically located on the eastern branch of the Andean Cordillera, allows sampling air masses from the Altiplano, Amazon forest, Pacific Ocean, and the La Paz/El Alto urban area (~2 million inhabitants). In addition, measurements of the total atmospheric column abundance of CO2, CH4, CO, and H2O were made by the EM27/SUN FTIR spectrometer, installed in El Alto city (4100 m a.s.l.), the first of its kind in the Andean region. This work aims to analyze the concentrations of the surface GHG measurements, relying on other variables and analysis of back-trajectories for this purpose. Furthermore, it explores the relationship among satellite data (TROPOMI), the CAMS high-resolution forecast model, and ground-based measurements.

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CarbonBridge - Connecting GHG satellite measurements with ground based measurements through vertical profiles.

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

For several decades, aircraft, and now balloon, vertical profiles of greenhouse gases (GHGs) have provided a critical constraint for satellite retrievals, forward and inverse models, and for our basic understanding of the carbon cycle and GHG budgets. Despite the powerful constraint that vertical profiles provide, planned campaigns and routine profiling programs are globally sparse and insufficient, given the challenges of interpreting remote sensing measurements that depend on significant bias corrections and uncertain transport models.

Recent global aircraft campaigns, commercial aircraft measurements, routine light aircraft sampling, and balloon-based platforms provide us with robust measurement technologies that enable an operational, instead of research-based, approach for capturing profiles of GHGs. However, it will require significant effort and international collaboration to achieve the spatial and temporal coverage needed to bridge between surface and spaceborne GHG observations. We propose a multi-national, multi-institutional and multi-platform approach, which seeks to use regular measurement campaigns, routine sampling from flights of opportunity on high-use (e.g. commercial and government) aircraft, and operational balloon sites. The resulting network will enable validation of satellite measurements, improved understanding of variability in GHGs throughout the troposphere and better understanding of the role that vertical mixing has in vertically distributing GHGs. It is important that the global community recognizes this opportunity and acts together to leverage these new possibilities.

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Tussock Tundra CH_4 Fluxes are Heterogeneous and Sensitive to Spring Conditions: An NGEE-Arctic Study at Council, Alaska

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

Arctic tussock tundra is often treated as one plant community for modeling and projecting greenhouse gas fluxes, but fine-scale heterogeneity in thaw, and thus hydrology, can have large impacts on greenhouse gas fluxes. We measured CH_4 exchange and ecosystem properties between 2017-2023 near Council, Alaska (AmeriFlux site US-NGC), as part of the Next Generation Ecosystem Experiment (NGEE-Arctic). The flux tower's northern footprint was moderately dry while the southern section contained inundated thermokarst features with different thaw depth, soil moisture, and temperature. Soil thawed earlier in spring in the non-thermokarst areas, but by July thermokarst features had a thaw depth of 1 m almost a month before those in the drier, upland areas. While there was little interannual variation in meteorological conditions in summer, variation in spring conditions dictated CH_4 fluxes at the site. The highest CH_4 fluxes occurred in 2019 [growing season average 20.1 nmol $m^{-2}s^{-1}$], which had a mild, wet spring (snowmelt 24 May). The lowest fluxes were in 2022 [growing season average 5.8 nmol $m^{-2}s^{-1}$], when spring was cooler and drier (snowmelt 29 April). In all years, the influence of thermokarst methane hot spots was clear in footprint-averaged fluxes. The tundra had heterogeneous CO_2 and CH_4 fluxes, in space, seasonally, and interannually. These were associated with wetland plants (model plant functional type under development) and with thermokarst and weather impacts on snow and subsurface moisture and temperature, pointing to the need for better representation of thermo-hydrology in land models.

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Investigation of CO_2 sources, variability and trends in Mexico City

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

Efforts to reduce CO_2 emissions from large urban centers, such as the Mexico City Metropolitan Area (MCMA) with its >22M inhabitants, will be crucial in reaching the needed goals for minimizing the impacts of climate change. Column-integrated concentrations of GHG have been performed in and around the city since 2012 with FTIR solar-tracking spectrometers, and an intensive field campaign (MERCI-CO2) that included 7 FTIR systems was carried out in 2020/21, as part of a fruitful French-Mexican collaboration, complementing the 2 in situ analyzers operated continuously in urban and background sites. A modeling system that includes inputs from weather parameters, local and global inventories and biogenic flux estimates was implemented. Data from ground observations and satellite instruments have been assimilated to quantify, with an analytical Bayesian technique, the emissions of CO_2 in the MCMA. Results from our comparison between the simulated and observed concentrations and the urban-rural gradients obtained from OCO-3, FTIR ground-based and surface in-situ observations, as well as the corrected emissions after the inversion, will be presented. Independent studies using long-term FTIR data show that the CO/CO_2 and HCl/CO_2 ratios can be valuable parameters to estimate CO_2 emissions from urban activities and volcanic emissions, respectively. We show how a detailed time- and space-resolved study linking observations to surface fluxes has the potential not only to improve our knowledge of the source's magnitude and distribution, but also to capture the changes over time produced by extraordinary events (COVID-19, ENSO, etc.) and by the actions to reduce the emissions.

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Quantifying the Total Water Available to trees through water fluxes measurements at 14 European forest sites

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

Historically, eddy covariance (EC) measurements have been widely used to quantify the Net Ecosystem Productivity, i.e. the carbon balance, of ecosystems. Less attention has been paid to EC measurements of water vapour fluxes which quantify the Actual Evapotranspiration (AET). The latter have been used to assess the closure of the energy balance, or to estimate canopy conductance, but rarely to establish a water balance. Here we use AET and precipitation measurements to calculate the cumulative water deficit (CWD), i.e. the running difference between AET and precipitation, at 14 ICOS forest sites over the period 2016-2023. A negative CWD value indicates that water has been mobilised from the soil by the trees to ensure their transpiration. In case of strong drought, the maximum CWD value quantifies the total water extractable from the soil by trees, that we term the Total Available Water (TAW, in mm). TAW is a critical parameter in ecosystem and land surface models. We quantify TAW to reach 230 ± 115 mm at the 14 ICOS forest sites studied. In most sites, this is more than two times the soil water holding capacity calculated from pedotransfer functions applied to soil characteristics compiled in the European Soil Data Center (ESDAC). We discuss the implications of these new TAW estimates on the parameterization of ecosystem and land surface models used to simulate the water and carbon balances of forests.

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Low CH_4 emission level by Eddy Covariance observation in water-efficient paddy Rice practices in central Taiwan

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Paddy rice, a key food and economic crop in East Asia, has been under scrutiny due to methane (CH_4) emissions during flooding, a concern highlighted at COP28. To address this, water-efficient methods like spike-watering are being promoted. This study, conducted from February to June 2023 in Taichung City, Taiwan, examined CO_2 and CH_4 emissions, filled missing data, and calculated the carbon budget using the eddy covariance method. The findings revealed that CH_4 flux is more heat-dependent during flooding but remains relatively stable with wind variations. Wind, however, is a significant factor during spike irrigation. The carbon budget showed a CO_2 sink of -17,634 kg-CO_2 per hectare, comparable to the carbon sequestered after rice harvest (16.5 tons CO_2 equivalent). The net CO_2 sinks were -6,573 kg-CO_2 per hectare, with a CH_4 emission of 21.4 kg-CH_4 per hectare (equivalent to 1,647.8 kg-CO_2). Given these results, CH_4 emissions cannot be overlooked when considering the carbon sink and its components. The study found that CH_4 emissions peak (0.04 µmol/m2/s) during flooding and field drying, both of which are water management-related. However, in water-efficient operations, CH_4 levels are low according to some paddy rice reports. Therefore, water-efficient practices not only conserve water but also reduce CH_4 emissions. Peak phases among GHGs, CH_4, CO_2, and latent heat fluxes, were analisied to understanding the process of the surpressed CH_4 emission in the field.

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Revisit the theories for below-canopy eddy covariance measurements in a karst forest in southwest China

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

The karst region occupies about 20% of the global terrestrial area and typically consists of complex and various carbon cycling processes. Because of the geomorphological and hydrogeological characteristics, it is still challenging to estimate the carbon budgets of the heterogeneous karst ecosystems. The below-canopy eddy covariance (EC) system can provide a unique opportunity to directly measure the net CO_2 exchange between the forest floor and the atmosphere. However, due to a lack of theoretical understanding of the fluid dynamics in the trunk space, application of the below-canopy EC technique requires more profound theories especially for forests situated in a complex terrain, such as the karst forests.

In this study, we will revisit the micrometeorological theories for the below-canopy EC measurements based on mass conservation, footprint theories, turbulent structures and (co)spectra analyses. With these theoretical understandings and validations, we will present some preliminary results on the one-year EC flux data collected from our site located in a karst primary forest in southwest China. Our study will provide some insights into measuring the forest floor CO_2 fluxes in a complex forest site using the below-canopy EC approach and a baseline estimate of the forest floor contribution to the karst forest carbon budget.

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Net Ecosystem Productivity of a mature temperate deciduous oak forest: comparing flux and biometric estimates

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

The eddy covariance (EC) technique provides an estimate of the net ecosystem productivity (NEP). Since its inception, questions have emerged regarding the ability of EC to accurately measure NEP. Here we compare NEP estimates of a mature, 150-yr old temperate oak forest (Fontainebleau-Barbeau, ICOS FR-Fon), established over 2007-2021. The NEP_EC of this 150-yr old forest is of 494±72 gC m-2 yr-1 (i.e. 6920 gC m-2 over 2007-2021), which places it in the high range of data for mature temperate deciduous forests. Over the same period, carbon stock increased by 3250 gC m-2 in woody tissues and 1440 gC m-2 in soil organic carbon. The biometric estimate of NEP in this forest thus reaches 67% (= (3250+1440)/6920) of NEP_EC. Reasons for this discrepancy may be : (1) the FR-Fon flux tower underestimates ecosystem respiration, as suggested by measurements of soil respiration and below-canopy EC fluxes, probably in relation to the site location at the edge of a plateau overlooking a river 50-m below ; (2) the fine root carbon stocks has increased and should be added to the biometric estimate of NEP. Our biometric estimate of NEP shows that though 80% of long-term carbon storage occurred in woody biomass, 20% ended in the accretion of the soil organic carbon stock. This is equivalent to 10 per mil increase of the SOC stock per year, coherent with trends reported for forest soils in France, Germany and Finland.

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From Monoculture to Diversity: Spontaneous tree growth and carbon dynamics after Coniferous removal at a humid temperate forest site

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

In September 2013, 8.6 hectares of Norway spruce (*Picea abies*) monoculture were cleared in the Eifel National Park, Germany, and left to spontaneous regrowth of the expected deciduous forest matching the site's climate and soil conditions. The area is located within the 38.5 hectare experimental catchment "Wüstebach" (50° 30'N, 6° 19'E, 595 to 630 m a.s.l.), one of the core investigation sites of TERENO (TERrestrial ENvironmental Observatories, https://www.tereno.net). Here, the exchange of energy and matter fluxes between spruce forest and atmosphere were monitored by an ICOS-associated eddy-covariace tower (DE-RuW) since 2010. A second station was installed within the newly established clearcut in 2013. Due to game (boar and deer) pressure, 2 hectares of the clearcut were additionally fenced. Over the first ten growing periods (2014-2023), the area notably shifted from a CO_2 source to a sink within eight years. The analysis focuses on the flux components, gross primary productivity, season length and peak fluxes and compares the spruce forest with the regrowth of the clearcut. Data on species, height, and diameter of regrowing trees, collected inside and outside the fence, show dominance by rowan (*Sorbus aucuparia*), propagated by birds, followed by wind-dispersed spruce and birch (*Betula pendula*). Rowan and birch grow twice as fast as spruce, with growth notably enhanced inside the fence, especially for rowan. This study provides rare insights into the dynamics of forest regeneration and the associated changes in carbon exchange.

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A multifaceted approach for urban methane sources identification in Melbourne, Australia

Jhonathan Ramirez Gamboa, Zoe M. Loh, Christopher G. R. Caldow, Nasimeh Shahrokhi, Cathy M. Trudinger, Elise-Andre Guerette, Ann Stavert, Ray Langenfelds, Blagoj Mitrevski, Darren Spencer, Christopher T. Roulston, Paul Krummel

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Theme

1. Isotopes and other tracers for studies of methane sources and sinks

Abstract Text

Methane (CH_4) is a potent greenhouse gas, and Australia's commitment to the Global Methane Pledge aims for a 30% reduction in emissions by 2030 (relative to 2020 levels). To achieve this ambitious goal, a deeper understanding of urban and regional methane sources is critical. Recent work highlighted the need for an improved emission inventory for Melbourne. Essential to this is the expansion of the urban observational network, to better detect emissions and attribute sources.

We have recently increased the density of our in-situ network (from one site to four) and deployed methane isotope analysers at three key locations. These will be used to characterise emission plumes from potential large emission sources including water treatment plants and oil and gas refineries.

Besides expanding the in situ observation network our approach includes complementary mobile surveys targeting major known methane sources. These surveys utilise isotopic signatures and ethane measurements to refine source attribution. Alongside this, flask sampling for further discriminating tracers, such as nitrous oxide (N_2O) and synthetic greenhouse gases, will be deployed to identify emissions from wastewater treatment and landfills. This strategy provides a rich data set for source characterization and attribution. Additionally, analysis of historical observations of methane and other tracers measured at our primary site over the last decade will offer insights into how local emission sources have changed over time.

Here we present preliminary results of the network expansion, mobile surveys, and tracer exploration approaches to improve our understanding of urban methane in Melbourne, Australia.

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Urban-scale inversions of methane emissions for Melbourne, Australia

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Understanding methane emissions is essential for prioritising mitigation efforts and tracking progress in emissions reduction. However, methane emissions remain highly uncertain, particularly in urban areas. Methane emissions from several sectors, including waste management, energy and nearby agriculture, give urban emissions a particularly complex spatial structure. In this study, we focus on methane emission estimates for Melbourne, Australia. There are no national gridded methane inventories for Australia, so we explored global datasets, including the Emissions Database for Global Atmospheric Research (EDGAR), to estimate prior emissions. We also distributed national emission estimates using regional information on landfills, wastewater treatment plants and livestock; this appears to give a better representation of emission patterns than the EDGAR dataset.

To create more comprehensive and accurate emission inventories for Melbourne, observational data on methane mixing ratios in the region are essential. This study has initiated the expansion of the methane monitoring network in Melbourne, from one to four in-situ stations, complemented by drive-around surveys. We ran a chemical transport model forced with prior emissions and compared the resulting modelled mixing ratios with observations. The comparison suggests that further improvements are required to reduce the model mismatch with observations. We used a synthesis inversion to infer scaling factors for the different emission sectors from observations at the four stations. We also used a four-dimensional variational data assimilation inversion system to infer the spatial pattern of emissions. We will present results from these two inversion approaches.

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Building-resolved CO_2 simulations to estimate emissions of the city of Zurich

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Urban areas significantly contribute to global greenhouse gas (GHG) emissions and play an important role in emission reduction strategies. Monitoring urban GHG emissions is therefore essential for optimizing mitigation efforts and supporting city climate action plans. The emissions are typically quantified using "bottom-up" annual emission inventories. Although this concept is well established, it should be complemented by an observation based "top-down" approach employing high-resolution models to trace measured concentrations back to their sources.

In Zurich, a city-wide monitoring network comprising around 80 sites with mid- or low-cost CO_2 sensors was installed to test measurement setups and their role in the top-down evaluation of emissions. To simulate CO_2 concentrations and transport, we use the building-resolved GRAMM-GRAL model system (Graz mesoscale and Lagrangian Model). Our CO_2 simulations at 10 m resolution help to better understand CO_2 emissions and sinks in the city of Zurich.

We compare the CO_2 simulations with observations from the urban sensor network and evaluate the network's efficiency in capturing city-scale gradients, as well as the utility of the low-cost versus mid-cost sensors. Furthermore, we combine the observed CO_2 concentrations with the model using a Bayesian inversion approach to trace measured concentrations back to the different emission sectors. This approach helps to verify and optimize the city's emission inventory and supports its path towards net-zero emissions by 2040.

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The variability of terrestrial CO_2 fluxes in semi-arid regions of the Southern hemisphere as seen by GOSAT

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Terrestrial carbon fluxes in the southern hemisphere still exhibit large uncertainties due to limited in-situ measurements and a lack of comprehensive process understanding. Greenhouse Gases Observing Satellite (GOSAT) measurements of XCO_2 can be used in an atmospheric inversion using the model TM5-4DVAR to obtain net CO_2 fluxes in remote areas. To understand the drivers of the CO_2 variability, Dynamic Global Vegetation Model (DGVM) models such as TRENDY v.9 provide gross fluxes and offer additional insight.

We here discuss monthly net CO_2 fluxes from 2009-2018 from three different semi-arid regions in the southern hemisphere, i.e. Australia, South American Temperate region and South Africa. For all three regions we find that the DGVMs are not consistent suggesting different carbon dynamics. Despite similar landuse types, the DGVMs best matching the inversion results, differ across the regions.

However, we find that in all three semi-arid regions the seasonal increase in net ecosystem exchange (NEE) occurs shortly after the onset of rainfall. NEE is driven by an early increase in heterotrophic respiration, whereas the autotrophic respiration remains in phase with the GPP and is delayed with respect to heterotrophic respiration. This process strongly shapes the seasonal cycle in the semi-arid regions, and in Australia, dominates the interannual variation. Our findings suggest that soil rewetting processes in semi-arid areas play an important role in constraining the global carbon budget and should be represented more accurately in global carbon cycle models to improve the estimation of the global carbon budget.

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Is urban carbon sequestration a myth or a fact?

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Limited knowledge on urban biogeochemistry and a lack of holistic assessments that include every component of urban forestry jeopardize the effectiveness of policies that promote vegetation as a means of mitigating climate change. Integral assessments that include plants and soil, as well as carbon emissions associated with irrigation and gardening activities for maintaining aesthetic grounds, are required to determine the capability of urban greenery to offset anthropogenic emissions of carbon dioxide (CO_2). Plants remove CO_2 by photosynthesis; a large fraction is consumed in biomass production, especially by young trees; mature trees do so to a lesser extent. The rest is transferred belowground. Once there, much of it returns to the atmosphere by soil respiration, leaving only a small fraction in the soil that may later be lost through leaching. Only a tiny fraction makes it through the mineralization process, which takes hundreds to thousands of years. Also, do not forget about the gardening waste fate. In this context, this talk will explain how trees, turfgrass, and soil regulate carbon exchange in sidewalks, parks, gardens, and lawns, based on a series of unique field experiments conducted in Singapore and Mexico City. These included eddy covariance flux measurements, tree surveys, the development and application of allometric models, turfgrass sampling, and continuous soil respiration measurements. It is important to identify and implement gardening practices that promote carbon storage while reducing the impact of maintenance activities. Bear in mind that cities are disturbed ecosystems, thus urban vegetation cannot respond as a natural ecosystem does.

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Comparing the Environmental Response of Carbon Dioxide and Methane Flux Dynamics in a Boreal Bog and Fen

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

Peatlands store a large part of the global soil carbon. These carbon stocks are at risk of being released into the atmosphere, due to warming temperatures and lowered water table levels.
Peatlands can be classified as bogs and fens, depending on their water supply. Fens tend to be more nutrient-rich and less acidic. Because of these different environmental factors, different types of vegetation thrive in these ecosystems, with *Sphagnum* mosses being more abundant in bogs and aerenchymatous vascular plants in fens.
This research focuses on comparing carbon dioxide (CO_2) and methane (CH_4) flux response under different environmental circumstances at Siikaneva bog and fen, located in the boreal zone in Southern Finland. They share the same climate due to their close vicinity, being 1.3 km apart. Eddy Covariance data of CO_2 and CH_4 fluxes during the growing season from the years 2011-2016 was used in this research. Our preliminary results indicate that the bog shows milder temporal variability and is less responsive to changes in temperature. The emission peak of CH_4 happens later in the fen and lasts longer. Further, the CH_4 flux response of soil temperature is highest for the fen at 35 cm depth but at 20 cm depth for the bog.
Our further analysis aims to isolate weather anomalies and identify the difference in flux response to extreme weather events between the bog and the fen. We will answer further questions about the future responses of CO_2 and CH_4 fluxes in a changing climate for bogs and fens.

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Quality control and annual uncertainty of direct flux measurements to address greenhouse gas emissions and land subsidence in Dutch peatlands

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Theme

14. Leveraging Direct Flux Measurements Beyond Academia for Real-World Applications

Abstract Text

Flux measurements by the eddy covariance method have been crucial to advance our understanding of the exchange of energy and greenhouse gases (GHG). The declining costs of equipment and increased power efficiency of fast trace gas analysers has enabled the use of the eddy covariance method to address nation specific GHG challenges and to develop emission mitigation strategies. Peatlands are impressive stores of soil carbon and account for 30% of storage globally, despite only covering 3% of the land surface. The Dutch peatlands have been drained for centuries to create more arable land and were exploited as a fuel source. Drainage of peatlands causes in aerobic microbial peat oxidation, resulting in high CO_2 emissions and land subsidence. To meet emission goals, the Dutch government made a climate agreement to reduce peatland emissions by 1 Mton CO_2 by 2030. The NOBV project was set up to understand peatland GHG emissions and to determine optimal strategies to reduce GHG emissions. In this presentation, we introduce our EC network monitoring fluxes on Dutch peatlands and explore some of the challenges that nation scale flux networks have with data quality and control, with a focus on the effect on annual flux totals of CO_2 and methane (CH_4). We examine the balance between filtering of the data for quality and increasing statistical power for more certainty in the annual totals. Annual totals are important in our case to estimate peat oxidation, and real management and policy decisions depend upon the outcome of these totals.

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Spatially comprehensive modelling of methane emissions in northern latitude peatlands

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

Wetlands in general and specifically northern peatlands are an important natural source of atmospheric methane. This is particularly true for high latitudes since they are undergoing the fastest climatic changes, potentially affecting methane emissions from these ecosystems. Methane flux measurements are conducted across various northern latitude peatland sites using the eddy covariance (EC) technique, providing reliable estimates of ecosystem-scale methane fluxes for these ecosystems. However, these measurements generally originate from single sites, raising uncertainties on their spatial representativeness, considering that northern peatlands can occur as large heterogeneous units termed as peatland complexes. This further introduces uncertainties in global models benchmarked with these data, and the need for replicated ecosystem level methane measurements. Leveraging a network of four adjacent sites within the Kulbäcksliden peatland complex in Northern Sweden, half-hourly flux estimates based on EC measurements are related to environmental properties within the footprints from which they originate. These include high-resolution vegetation indices from Sentinel-2 satellite and unmanned aerial vehicle (UAV) images, peatland surface microtopography, spatially modelled water table depth, soil temperature, and site peat characteristics like C:N ratio or bulk density. Machine learning algorithms such as XGBoost or Random Forest are employed to disentangle the spatial complexities of the relationship between measured methane fluxes and their drivers. Results from this work provide a better insight on the contribution of different components of a peatland complex to methane fluxes and pave the way for more spatially and temporally comprehensive modelling of methane emissions from peatlands, particularly large peatlands or peatland complexes.

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Influence of Atmospheric Transport in Inversions using Greenhouse Gas Column measurements: A Study with MUCCnet in Munich

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Quantification of greenhouse gas (GHG) emissions is crucial for shaping climate action plans. The assessment of urban GHG emissions through the Bayesian inversion of column measurement data offers an effective method. Within this Bayesian inversion process, the quality of the emission estimates is dominated by the quality of the transport model. Understanding the impacts of various transport models can enhance the accuracy of emission inversion results.

This research utilizes EM27/SUN column measurements for Bayesian inversion in Munich, spotlighting the influence of varying meteorological fields. We employ the European Centre for Medium-Range Weather Forecasts Reanalysis 5 (ERA5) and the Weather Research and Forecasting (WRF) model with distinct setups to drive the Stochastic Time-Inverted Lagrangian Transport (STILT) model, generating backward trajectories of particles and a background influence matrix. Various wind observations, including Doppler Lidar wind profiles, are utilized to assess and amend transport errors, quantifying the diverse transport inaccuracies inherent in Bayesian inversion. Moreover, the study incorporates WRF-Chem for forward modeling of greenhouse gases, using optimized emission inventory from the inversion to generate a greenhouse gas flux field for Munich. This approach allows for the evaluation of inversion effectiveness through comparison with actual flux measurements. This comprehensive assessment sheds light on the substantial impact of transport models on greenhouse gas Bayesian inversion, providing valuable insights that could inform future environmental policies and research in urban GHG monitoring.

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Scientist’s toolkit: How to get media visibility for your research?

Maria Luhtaniemi, Karlina Ozolina

ICOS ERIC, Helsinki, Finland

Theme

15. Science communication and outreach to increase the impact of climate research

Abstract Text

Climate science is vital to communicate to society, but far too many impactful research papers never break through to national or international media. While lack of resources is a known challenge in science communications, there are ways in which all of us can become better science communicators.

The purpose of this presentation is to share practical tips with scientists on how to use their own social media skills and presence to gain visibility for their research, for example, by using their personality and storytelling to showcase the heart behind their research project. Furthermore, this presentation highlights how to best make use of the resources available in scientific institutes or wider research networks. The practical session moves from sharing inspiring examples of science communications on social media to tips on how to shape an engaging narrative for your press release. To illustrate this, the session presents some successful communications, facilitated by the ICOS Head Office communications team, that brought visibility to studies from the ICOS community.

The purpose of this presentation is to provide ICOS scientists with more confidence, tools and inspiration for increasing the visibility of their research, either through their own networks or through utilising the skills and expertise of the communications teams of their institutions.

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Implementing shrub plant functional types to improve the representation of high latitude vegetation in ORCHIDEE

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

Under amplified global warming, high-latitude terrestrial regions are already experiencing observable changes in vegetation dynamics, including an Arctic greening linked to an increase in productivity and an expansion of shrubs across tundra ecosystems. Since these dynamics alter the local-to-regional carbon cycle and hold potential for global climate change feedbacks, it is important to capture such changes in plant traits and species distribution in global land surface models (LSMs) to improve their capability to represent current and future climate changes. However, the LSM ORCHIDEE, like several other LSMs, is lacking high-latitude plant functional types (PFTs), including shrubs, limiting its ability to capture these changes and their impacts on carbon and surface energy balances. To improve the representation of high-latitude vegetation and the model's ability to capture and project high-latitude greenhouse gas fluxes, we introduce several types of Arctic shrubs into the latest version of ORCHIDEE. The shrub PFTs differ from the model's boreal tree PFTs in their carbon allocation and resistance to harsher climatic conditions and have higher biomass stocks and carbon fluxes than boreal grasses, which dominate high-latitude regions in the current model version. We use observations of carbon fluxes, biomass and other plant traits to calibrate the model, by identifying shrub-dominated sites across the circumpolar region in the ICOS, FluxNet and other databases. This work lays the foundation to model important changes in high-latitude vegetation dynamics, such as shrubification, their interactions with snow and permafrost dynamics and their climate feedback potential in ORCHIDEE.

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Capabilities of CH_4 source apportionment using atmospheric $^{14}CH_4$ measurements: Switzerland as a case study

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Theme

1. Isotopes and other tracers for studies of methane sources and sinks

Abstract Text

CH_4 is the second most important anthropogenic greenhouse gas after CO_2. While biogenic emissions of CH_4 (from agriculture, waste management or wetlands) contain present-day atmospheric radiocarbon (^{14}C) levels, CH_4 derived from fossil sources is ^{14}C-free so that $^{14}CH_4$ measurements can be used for source apportionment. A dedicated setup to analyze $^{14}CH_4$ was developed at the Laboratory for the Analysis of Radiocarbon with AMS (LARA), University of Bern. Typical samples are 60L of atmospheric air collected in bags, which, after extraction result in about 60µg carbon in CH_4-derived CO_2 form, enough for a ^{14}C gas measurement on an accelerator mass spectrometer equipped with a gas interface system.

Since 2019, biweekly air samples have been collected at six sites in Switzerland: the high-altitude research station Jungfraujoch considered as a European continental background station, four tall towers distributed across the Swiss plateau, and an urban site in Bern. In parallel, an atmospheric $^{14}CH_4$ transport model was developed to simulate $^{14}CH_4$ values for each sample. It is based on the Lagrangian particle dispersion model FLEXPART, CH_4 emission inventories, *a priori* $^{14}CH_4$ signatures for each emission type and the regional weather model COSMO. $^{14}CH_4$ emissions from European nuclear power plants (NPPs) are also taken into consideration.

This contribution will present the *in situ* $^{14}CH_4$ measurements as well as corresponding simulations and emphasize that the emissions and transport of $^{14}CH_4$ emitted from European NPPs are greatly influencing the overall signal measured over the Swiss plateau, making CH_4 source apportionment very challenging.

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In-situ NO_x observations using the German ICOS tall tower setup

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

In-situ greenhouse gas (GHG) measurements on ICOS tall towers continuously provide high-quality and high temporal resolution data on atmospheric dry mole fraction in the lowest few hundred meters of the atmosphere. Supplementary measurements of species that are co-emitted by anthropogenic activities, such as nitric oxide (NO) and nitrogen dioxide (NO_2), could aid in attributing these GHG observations to specific emission sectors such as transportation, industry and energy production. These short-lived trace gases are observed within the European Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS).

Expanding ICOS GHG observations with ACTRIS NO_x (NO + NO_2) measurements will provide valuable insights into emissions from different sectors. At ICOS tall tower sites, long in-take lines extending up to a few hundred meters, are used to draw ambient air into a temperature-controlled container, housing the GHG analyzers. Utilizing the existing infrastructure for NO_x observations demands a thorough characterization of the sampling setup, particularly considering the reactivity of NO and NO_2 and surface reactions in the inlet line.

Here, we present a potential configuration for conducting in-situ NO_x observations at German ICOS tall tower sites and its associated uncertainties using the Cavity Attenuated Phase Shift (CAPS) technique. Our theoretical and experimental analysis considers potential inlet line effects, including chemical reactions occurring during long residence times in the sample line. Furthermore, we will present ambient air NO_x measurements obtained from a setup used at German ICOS tall towers.

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Luke GHG flux network on northern managed ecosystems

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

Nordic countries are commonly seen as countries of wild boreal forests, wetlands and lakes. However, majority of forests in Finland and Sweden are managed for forestry and both countries have significant agricultural sectors that provide self-sufficiency in basic agricultural products. Agricultural land covers 7-8 % of land area, and with the potential decline in agricultural conditions in Southern Europe, there may be a pressure to increase agricultural production in the future. Of forest land, more than 90 % is under economically driven management, as forestry is a major economic sector in both countries.

High-level data is prerequisite for quantification and understanding the GHG balances of the managed ecosystems. To contribute to these needs, Luke operates five eddy covariance flux sites in agricultural systems and one at a recently clear-cut and seeded drained peatland forest. The agricultural sites consist of both mineral and organic soils. Maaninka-Anttila (FI-Ant) forage grass site on mineral soil is undergoing the ICOS labeling process to become a Class 2 ecosystem station. The forest site provides data on GHG exchange of a clear-cut forest on drained nutrient rich peatland to compare, adjacent to a flux site measuring GHG-balance of a continuous cover forestry.

All the sites measure the fluxes of the three major GHGs (CO_2, CH_4, N_2O) in identical set-ups. The data is processed centrally with ICOS compliant data processing pipeline. We will present the Luke flux measurement network, data pipeline, and provide examples of the means and variability of GHG fluxes across our managed ecosystems.

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Story on the attempt to industrialize low-cost eddy-covariance measurements

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Theme

14. Leveraging Direct Flux Measurements Beyond Academia for Real-World Applications

Abstract Text

Greenhouse gas flux measurements start to play increasingly important role outside academia in assessing carbon sinks of different ecosystems and land-use types. In order to monetize and deploy dense carbon assesment solutions in future carbon markets, more low-powered and low-cost flux systems should be deployed. Low-cost sensors fulfilling the requirements for scientific applications are increasingly needed.

We present a case study where Vaisala company in collaboration with the University of Helsinki combined their industrial and academic expertise to create an operational eddy covariance (EC) setup with a low-cost gas analyser. The setup was intended to be affordable, low-powered, easy-to-use, and require minimal maintenance. Created prototype EC station represented a compromise in terms of accuracy, reliability, and affordability. We secured joint funding for a post-doctoral researcher from the Finnish Research Impact Foundation. The project lasted two years and involved significant in-kind contributions from both Vaisala and university.

A working prototype was co-developed, and field tested against a scientific reference EC set-up. The project had special emphasis on response time, reduced sampling frequency, simultaneous measurement of water vapor, and temperature-related autocalibration. The results achieved at the end of the project were very promising, leading to plans for continued work both at Vaisala and university.

However, a deeper market analysis revealed that the market in the year 2022 was not sufficiently large to justify Vaisala's investments. Therefore, Vaisala halted further development of the sensor.

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Biogenic CO_2 fluxes in different urban vegetation types in Helsinki, Finland

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Many cities aim for carbon neutrality, prompting interest in the potential of urban vegetation as carbon sinks. In addition, accurate estimation of emission reductions requires understanding the size and dynamics of natural carbon fluxes. However, the heterogeneous nature of urban vegetation and environmental conditions poses challenges for comprehensive measurement efforts and thus sets expectations for carbon cycle modelling. This study evaluates the performance of three models - JSBACH, LPJ-GUESS, and SUEWS - in estimating biogenic CO2 fluxes and carbon sequestration rates across various urban vegetation types in Helsinki, Finland, including irrigated and non-irrigated lawns, park trees, and urban forests. Environmental parameters such as soil moisture, temperature, sap flow, leaf area index, instantaneous photosynthesis, soil respiration, and net ecosystem exchange were analyzed. Additionally, JSBACH was tested for dry and mesic urban meadows. Results indicate that the models effectively simulate seasonal variations and weather event effects on carbon fluxes and related factors. However, validating absolute fluxes proved challenging due to observational limitations, especially for mature trees and net ecosystem exchange measurements, which also include some anthropogenic emissions in urban areas. Despite these challenges, irrigation emerged as a key factor, usually enhancing carbon sequestration, with tree-covered areas exhibiting higher rates compared to grass types on an annual scale.

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Diurnal profiles of volatile organic compounds emitted from an agricultural area

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Theme

2. Exchange of reactive gases and aerosols between the land surface and the atmosphere in natural and managed ecosystems

Abstract Text

Biogenic (BVOCs) and anthropogenic (AVOCs) volatile organic compounds play pivotal roles in atmospheric chemistry due to their fast reactivity and high potential for tropospheric ozone formation. Diurnal courses of BVOCs and AVOCs over an agricultural site were measured using the PTR-TOF technique from spring to autumn of 2023. The site, Křešín u Pacova (CZ; 49.572N, 15.08E), forms a part of the ICOS station network (atmosphere station, class 1) and is covered by arable land with patches of forests. Here we present diurnal courses of monoterpenes, isoprene, and 2-methyl-3-buten-2-ol (232MBO). The results show that the hot summer period in July is associated with high nighttime concentrations of monoterpenes due to boundary layer shrinking. In contrast, concentrations of other BVOCs (e.g., 232MBO, isoprene) peak during the central hours of the day, suggesting that their emissions are likely sunlight-driven.

To identify pollution related to the operation of the research infrastructure, the ratio of toluene and benzene concentrations was also investigated. Typically, the ratio is high (>1.5) at polluted sites and close to one at clean locations. Here, overnight maxima amounted to 1.6, indicating that fresh AVOC emissions are close to the sampling point. Oil drops and leakage from diesel engine of the atmospheric tower elevator was identified as a likely source of such emissions.

Acknowledgements

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Quantification of Hotspot Emissions Using Ground-Based Spectral Imaging of Methane and Carbon Dioxide

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Spectroscopic imaging of greenhouse gases (GHG) from satellites and planes is an emerging tool for quantifying GHG emissions occurring in urban contexts. Particularly hotspot sources of carbon dioxide (CO_2) and methane (CH_4), such as coal-fired power plants, landfills, and oil & gas facilities, are accessible by remote sensing methods. Precise quantification of these hotspots is essential to discriminate their contribution to area-wide budgets from other source sectors.

We operate a ground-based spectral camera in a stationary viewing geometry, enabling repeated observations of a source over prolonged periods under km-scale distances. An adapted matched filter retrieval quantifies column enhancements of CO_2 and CH_4 from the recorded solar absorption spectra in the 2.0 µm and 2.3 µm regions, respectively. Our precursor studies demonstrate our ability to quantify enhancements in emission plumes from strong point sources, like CH_4 from underground coal mining (Knapp et al., 2023) or CO_2 from coal-fired power plants (Knapp et al., 2024). High-frequency plume imaging enables emission estimation with sub-hourly (CH_4) to hourly (CO_2) temporal resolution for emission hotspots, complementing existing monitoring capacities.

We will operate the camera at the Pinto landfill in Madrid, Spain, during the Madrid Methane Remote Sensing (M-MRS 2024) field campaign in summer 2024. Landfills are intermittent and diffuse sources of CH_4 with significant uncertainties and mitigation potential. This proof-of-concept campaign aims to evaluate our methodology for landfills, and we intend to present initial findings regarding methane plume observations and emission estimates.

Knapp et al., 2023 (doi: 10.1088/1748- 9326/acc346)

Knapp et al., 2024, (doi: 10.5194/egusphere-2023-1857)

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Provisional title :Modelling N_2O emissions from cropland in clay soils

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Provisional abstract :

Cultivated soils are a major source of global anthropogenic N_2O emissions due to the use of N fertilizers. The two main processes responsible for these fluxes are (1) nitrification, the oxidation of ammonium into nitrite and nitrate, and (2) denitrification, anaerobic microbial respiration. These fluxes are still poorly understood because they are difficult to measure and model due to their sporadic nature. They depend on numerous factors that are strongly influenced by the nature of the soil and so far few studies have focused on clay soils.

Therefore, the aim of this study is to test two process-based modules, NOE and NOE2, in their ability to simulate N_2O fluxes on highly clayey cropland soils. For this we have used fluxes measured during 3 years with automatic chambers at two ICOS sites (FR-AUR and FR-LAM) located in South-West France.

Preliminary results show that the N_2O fluxes dynamics are simulated correctly with default parameters for both models (RMSE of 7.68 and 5.15 , for NOE and NOE2 respectively). Yet we consider that a specific parametrisation for clayey soils of those models could improve their performances, in particular for the denitrification potential parameter. Therefore, the results of a site-specific bayesian calibration of these parameters will be presented and evaluated. In the future, NOE or NOE2 will be coupled to the SAFYE-CO_2 model, which enables the spatialized simulation of biomass, water and carbon cycle at intra-plot scale, in order to simulate spatialized N_2O fluxes.

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The CDRatlas: A platform to visualize the potential of CDR

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Theme

13. In situ data for climate and other environmental services and policy support

Abstract Text

The repercussions of climate change and measures for its mitigation are among the most pressing challenges of modern society. Emission reduction scenarios indicate that negative emissions, i.e. "carbon dioxide removal" (CDR), are a necessity to reach the goals of the Paris Agreement. However, the development and implementation of CDR is constrained by limited accessibility of relevant information. To overcome this, we build an open access web tool, termed the CDRatlas, that provides relevant information on the implementation and potential of commonly considered marine and terrestrial CDR approaches. The information is presented on an intuitive and interactive web-platform by a combination of (1) process chain assessments, (2) geospatial data visualization and (3) additional text-based information. The process chains identify the relevant steps for the implementation of a respective CDR approach. Based on these steps, data is gathered and presented in form of map layers or as text-based information. This will allow decision makers to identify the ecological and technological readiness and capacities along the relevant steps for the implementation of the depicted CDR measures. This enables the identification of measures for the direct implementation and strategic development of CDR. In addition, all information and data are openly accessible and either harvested from existing platforms or stored in data repositories. Further, displayed information is presented in an easily understandable manner, allowing non-experts to get an overview of the subject. As a result, the CDRatlas will serve as a knowledge interface from the scientific community to members and actors within society.

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Global CO_2 inversions with chemical production from CO

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Every year, a top-down estimate of the global carbon budget using atmospheric inversions is performed as part of the Global Carbon Project (Friedlngstein et al., 2023). Furthermore, other initiatives, such as OCO-2MIP (e.g Crowell et al., 2019), provide a similar ensemble of top-down estimates of global CO_2 fluxes. A common assumption in these inversions is that all CO_2 that is measured in the atmosphere is also emitted to the atmosphere in the form of CO_2. In reality, part of the atmospheric carbon is emitted in a more reduced form (e.g. CO or CH_4) and is later oxidised in the atmosphere to form CO_2. This effect is expected to influence the CO_2 flux estimates from inversions (e.g. Enting & Mansbridge, 1989; Sunthatalingam et al., 2005; Wang et al, 2020). Here, we present the results from atmospheric inversions that include the atmospheric chemical production of CO_2 from CO, which is constrained by an independent atmospheric inversion based on satellite CO column retrievals. Our long timeseries results (2000-2021) allow for the assessment of robust seasonal cycles and trends in the effect of the atmospheric CO_2 production on the global and regional CO_2 inversions Furthermore, we investigated the effect of two different data sampling strategies.

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Atmospheric methane behavior in an Atlantic coastal environment in the Southwestern Europe.

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Theme

1. Isotopes and other tracers for studies of methane sources and sinks

Abstract Text

Atmospheric methane (CH_4) was registered in an Atlantic coastal area of Southwestern Europe, El Arenosillo observatory. The study covered a four-year period (September 2019 – December 2023). Based on daily averages a short-term trend of 12.1 ± 1.1 nmol mol^{-1} year^{-1} was found. Regarding the monthly evolution, the maximum was measured in winter (~1994 nmol mol^{-1}) while the minimum was found in summer (~1961 nmol mol^{-1}). A seasonal diurnal cycle was also observed, with peaks at 7:00 – 8:00 UTC and minima registered at 18:00 – 19:00 UTC. To investigate its dynamics, we studied CH_4 in an atmosphere governed by synoptic scale. Atmospheric dynamic was analysed with the wind fields from ERA5 data reanalysis and the air masses pathways with the back-trajectories computed with the HYSPLIT model. While the CH_4 horizontal distribution was explored with the TROPOMI observations. Baseline CH_4 levels (~1960 nmol mol^{-1}) were collected under the influence of Atlantic air, while an increase from 20 to 80 nmol mol^{-1} was found under the influence of continental airflows, coming from the inland Guadalquivir valley.

During the development of mesoscale processes (such as sea-land breezes), frequent in this coastal area, no increase in CH_4 was observed. However, the horizontal distribution from TROPOMI showed an accumulation over the marine area of the Gulf of Cádiz. Among other objectives, the ongoing CH_4 observations will be used in future studies, to identify potential changes in its trend, as well as to understand the potential contribution of the CH_4 transported from the Western Mediterranean Basin and other areas.

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Combined CO_2 and O_2 measurements for process-specific partitioning and carbon budgeting

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

We measured combined CO_2 and O_2 measurements at different locations in Switzerland. On the roof of our laboratory at the University of Bern, we installed an aspirated intake and are able to distinguish urban combustion from biogenic signals based on their differences in oxidation ratios (OR). At the tall tower Beromünster, we have installed five inlet systems at different heights. This allows us to observe differences of biogenic OR values during night (respiration) and day (combination of photosynthesis and respiration) as well as follow the dilution process of biosphere signals originating from the soil and surface due to mixing with atmospheric air at different intake heights. Additionally, at Jungfraujoch combined CO_2 and O_2 measurements allow us to partition the CO_2 emissions due to its main sink reservoirs, i.e. the ocean, land and the atmosphere. The presentation will highlight the potential of combined CO_2 and O_2 measurements for the quantification of OR values and CO_2 emission partitioning.

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Impact of climate extremes on air-sea CO2 exchanges in the North Western Mediterranean Sea: A study based on the MOOSE network

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

The Mediterranean Sea is considered to be a "hotspot" for climate change with effects occurring on faster time scales than the global ocean. It is particularly affected by extreme climatic events with very high temperatures at the sea surface during summer and reduced ventilation of intermediate and deep water masses by winter convection as observed by moored time series. In the framework of the MOOSE sustained observing network (CNRS-INSU), observations of inorganic carbon chemistry based on discrete sampling from the surface to the bottom have been collected since 2010 in the North-Western Mediterranean Sea during monthly oceanographic cruises at fixed stations and every year during a basin scale cruise (MOOSE-GE, https://doi.org/10.18142/235).

In this study, the main results on the seasonal variability of CO_2 exchanges between the atmosphere and the surface, intermediate and deep ocean and on long-term changes (decadal trends) in inorganic carbon chemistry will be presented. The main objectives of this study are to assess (1) the effect of extremely hot summer temperatures on the air-sea CO_2 exchanges at a seasonal scale and (2) the effect of reduced winter convection on the inorganic carbon content of the upper water column at the scale of decadal trends from individual stations to the entire N.W. Med. Sea. In conclusion, we propose improvements of the MOOSE network's inorganic carbon chemistry observation strategy to better monitor and understand the effect of climate extremes on CO_2 fluxes.

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A MRV system implemented as fully automated reproducible self-documenting workflow

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

The ICOS research infrastructure collects, maintains and supports a large range of high quality and long-term greenhouse gas observations in its FAIR data repository Carbon Portal (CP), together with inventory, modelled surface fluxes and ancillary data. All of these receive unique persistent identifiers as key pre-requisite for achieving reproducible scientific workflows.

Here we present a self-documenting, fully reproducible workflow for our inverse carbon model system LUMIA that builds on the CP infrastructure and methods. The Lund University Modular Inversion Algorithm (LUMIA) has been developed at the Lund University hosting department of CP for inverse modelling of carbon dioxide and (isotope resolved) methane. The model uses as input observational and prior flux data like those mentioned before. The overarching goal of this so called top-down inverse method is to provide optimised emission fields based on observations. Next to common and scientific interest, the method also can inform policy makers on the progress in reaching the goals of the 2015 Paris agreement, through independent estimates of emissions and natural fluxes. For this purpose an open, flexible, transparent, modular and reproducible system like presented here is needed.

The design goals include using the system as demonstrator of the general principle of the use of inverse modelling tools based on simplified and reduced datasets, to perform network design for observational systems based on real and synthetic data sets, up to full blown regional inversions in a MRV (Measurement, Reporting and Verification) system based on all available data, including an analysis of uncertainties.

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Evaluation of Ground-Based PAR Quantum Sensors for fAPAR Estimation: Quality Control and Uncertainty Assessment

Rémi Grousset[1], Gabriele Bai[2], Christophe Lerebourg[2], Somnath Paramanik[3], Finn James[3], Jadu Dash[3], Ernesto Lopez-Baeza[4], Ana Perez-Hoyos[4], Alexander Knohl[5], Anne Klosterhalfen[5], Frank Tiedemann[5], Nadine Gobron[6], Marco Clerici[6]

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Theme

13. In situ data for climate and other environmental services and policy support

Abstract Text

Long term ground-based measurements are of prime importance for the validation of remote sensing methods for vegetation variables retrieval. While Digital Hemispherical Photography (DHP) measurements have traditionally been employed, Photosynthetically Active Radiation (PAR) quantum sensors have sparsely been evaluated as ground-based sensors for estimating fraction of Absorbed Photosynthetically Active Radiation (fAPAR). To leverage PAR data effectively, stringent quality control (QC) procedures and end-to-end uncertainty propagation are imperative. QC is crucial due to potential disturbances, including device variations, vegetation shadows, and cloud cover (especially under scattered clouds environment). We investigate four QC methods: comparison between above-canopy and below-canopy sensors, intensity prediction based on solar zenith angle, consistency of above-canopy sensor readings, and hull methods. Performance evaluation of these methods is conducted using a manually controlled dataset spanning fifty days. A first estimate of uncertainty budget is quantified following the principles outlined in the Guide to the Expression of Uncertainty in Measurement (GUM).

The Ground-Based Observations for Validation (GBOV, https://land.copernicus.eu/global/gbov), under the Copernicus Global Land Service, aims to establish a comprehensive database of ground-based land products and reference measurements. Evaluation and validation of the QC and uncertainty processing methods are performed within two GBOV PAR quantum sensor networks. The first network, situated in Hainich National Park, Germany, within an old-growth beech forest, comprises a single above-canopy node. The second network, located at the Valencia Anchor Station, Spain, within a Mediterranean vineyard, incorporates multiple above-canopy sensors.

We anticipate presenting the outcomes of our investigation during the forthcoming conference.

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The African Greenhouse Gas Budget (2010-2019): a synthesis of the most recent data and models

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

We developed a comprehensive African greenhouse gas (GHG) budget over the 2010-2019 time period as part of the REgional Carbon Cycle Assessment and Processes Phase 2 (RECCAP2). We incorporated bottom-up process-based models, data-driven remotely sensed products, and national GHG inventories in comparison with top-down atmospheric inversions, inclusive of lateral fluxes. For fluxes of particular importance in Africa (e.g. termites, herbivores and fire), we derived emission estimates from novel methodologies. We further constrained global woody biomass change products with high-quality regional observations. Net ecosystem exchange switched from a small sink of −0.61 ±

0.58 $PgCyr^{-1}$ in RECCAP1 (1985-2009) to a small source in RECCAP2 at 0.16 (-0.52/1.36) $PgCyr^{-1}$. Net bottom-up estimates of CO_2 emissions were 1.6 (-0.9/5.8) $PgCO_2yr^{-1}$, net CH_4 were 77 (56.4/93.9) $TgCH_4yr^{-1}$ and net N_2O were 2.9 (1.4/4.9) TgN_2Oyr^{-1}, showing similar trends to top-down atmospheric inversions. Land use change emissions (0.5 $PgCyr^{-1}$) are still higher than fossil fuel emissions (0.4 $PgCyr^{-1}$), and both are increasing. Africa still contributes ~4% of the global fossil fuel emissions, but emits nearly 40% of the global emissions from land use. Overall, the continent contributes 3-5% of the growing amount of GHGs in the atmosphere. Uncertainty remains high despite improved methodology, highlighting the need for increased efforts to address Africa-specific data gaps and develop models that integrate Africa-specific processes. Nevertheless, this budget provides a baseline against which to assess policy and intervention effectiveness, and a tool to identify sectors and regions that should be prioritised for improving livelihoods and increasing carbon storage.

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GAW-qc: A data science-based dashboard to promote near-realtime quality control of atmospheric composition measurements

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Theme

16. Continuous Learning in a changing world - Teaching and learning novel tools & methods used for measurement techniques', data & policy

Abstract Text

The Global Atmosphere Watch (GAW) Programme of the World Meteorological Organization coordinates a worldwide network of ground-based in-situ monitoring stations that provide reliable scientific data on the chemical composition of the atmosphere. In the framework of the GAW Programme, the Quality Assurance/Scientific Activity Centre at Empa has developed an interactive dashboard based on data science to support station operators in timely detecting issues in their in-situ measurements of carbon dioxide, carbon monoxide, methane, and ozone concentration.

The application (GAW-qc), currently in beta testing, makes use of a mixture of purely data-driven and hybrid anomaly detection techniques. It exploits historical measurements as well as the archive of physics-based numerical forecasts by the Copernicus Atmosphere Monitoring Service (CAMS). The representativeness of the latter is improved through machine learning, resulting in more reliable predictions for the target station.

GAW-qc allows station operators to upload their latest measurements, visualize the data with different temporal aggregations, and easily detect anomalous values using just their internet browser. First case studies indicate that this process can facilitate the timely detection of malfunctionings in the analytical setup and reduce the ingestion of erroneous data into the international data repositories. It may become a game-changer towards reliable, comparable and traceable world-wide datasets in the field of air quality and greenhouse gases.

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Do N_2O fluxes and N_2O production processes differ under different grassland management (overseeding legumes vs. organic fertilization)?

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Nitrous oxide (N_2O) is an important greenhouse gas, and agriculture is the main contributor to anthropogenic N_2O emissions. To mitigate N_2O fluxes from agricultural areas, the underlying N_2O production processes and their environmental constraints need to be better understood, and the effects of different management strategies on N_2O production need to be tested.
Thus, our aims were 1) to investigate the effect of overseeding legumes versus slurry N fertilization on N_2O fluxes and 2) to compare N_2O production processes under the two grassland N fertilization strategies. We conducted a N_2O-mitigation experiment at a temperate grassland over five years, replacing N inputs via organic N fertilization (slurry) with biological N_2 fixation via overseeding legumes (clover). N_2O fluxes were measured with eddy covariance, while N_2O production processes were assessed using a stable isotope approach. The site preference (SP, intramolecular distribution of ^{15}N within N_2O) served as indicator for nitrification and denitrification. N_2O fluxes showed net N_2O emissions on the annual scale, which were lower in the oversown legume parcel (3.2 kg N_2O-N ha^{-1} yr^{-1}) compared to the parcel fertilized with slurry (5.8 kg N_2O-N ha^{-1} yr^{-1}; 4-year average). SP values (7.5±4.9‰; average±SD, n=111) did not differ between parcels, and indicated denitrification as the main N_2O production process, independent of grassland management. Replacing organic fertilization with overseeding legumes proved to be a suitable N_2O mitigation measure, with further environmental benefits such as reduced nitrogen leaching, albeit with a trade-off for carbon sequestration.

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A high-resolution atmospheric inversion framework for CO_2 observations in Paris using GRAMM/GRAL

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Cities are carbon dioxide (CO_2) emission hotspots and exhibit multiple different CO_2 sources from various sectors in close vicinity. For a city to implement effective mitigation measures, the sector-specific emissions need to be known and changes in the emissions must be monitored on highest possible resolution.

We present a framework to estimate the emissions of urban areas. Atmospheric transport of CO_2 is simulated on high resolution using the model GRAMM/GRAL. By assuming hourly steady-state conditions and applying a match-to-observation algorithm, the model can simulate atmospheric transport with a horizontal resolution of 10m x 10m for cities. Conducting a Bayesian inversion approach described in Vardag and Maiwald, 2024, urban CO_2 emission can be estimated.

We apply the framework in Paris, France. The city is a European CO_2 emission hotspot and has set-up an ambitious climate plan with the goal to become completely carbon neutral by 2050. For the framework, prior information about the emissions is taken from inventories (TNO) and atmospheric CO_2 measurements are provided by ICOS Cities (Horizon Europe, PAUL project). We compare measured and simulated CO_2 enhancements and discuss implications for CO_2 emission estimation. We give an outlook on current limitations and further development of emission estimates.

Vardag, S. N. and Maiwald, R.: Optimising urban measurement networks for CO2 flux estimation: a high-resolution observing system simulation experiment using GRAMM/GRAL, Geosci. Model Dev., 17, 1885–1902, https://doi.org/10.5194/gmd-17-1885-2024, 2024.

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Three years of Eddy covariance measurements of a tropical forest in the Congo Basin.

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

The CongoFlux climate site in the Yangambi UNESCO biosphere reserve (0°48’52.0N, 24°30’08.9”E) hosts the first Eddy Covariance (EC) flux tower in the central Congo Basin. The site, recently labeled as an ICOS associated ecosystem station, was built in 2020 to address the lack of observations of the tropical forest ecosystems in Central Africa. We aim to quantify the net ecosystem exchange (NEE) and the water use efficiency (WUE) of the tropical forest in the footprint of the tower. A set of meteorological and hydrological data is recorded that could explain the seasonal patterns of NEE and WUE. In addition also soil respiration, stem respiration and gas exchange on leaf level scale are measured. Processing EC data still remains a challenge in the tropics. Tall vegetation and frequent low turbulent conditions call for attention to the storage correction term. Multiple set ups on the site were used to study the best way to handle the nighttime buildup of CO_2 in the canopy. The threshold for the friction velocity filtering, needs to be selected with care to minimize the influence of the frequent low turbulent conditions, while at the same time minimizing the amount of data that needs to be filtered out. Power cuts and data filtering result in many and sometimes large data gaps, which increase the importance of accurate gap filling techniques. We here present three years of processed EC data together with the challenges of an EC station in the tropical forest of the Congo basin.

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Soil CO_2 emission from different agricultural management practices

MANUEL ACOSTA, Lukáš Kokrda, Marian Pavelka

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

In agricultural cropping systems, the larger part of the carbon is stored in the soil. Improving agricultural practices has great potential to increase the amount of carbon sequestered in cropland soil. Promising approaches in recent years are changes in management practices and biochar application. We conducted soil CO_2 emissions (S_{CO2}) measurements on a maize (*Zea mays* L.) plantation using the chamber technique during three vegetation seasons (2021-2023) with different management practices (conventional tillage, no-tillage, biochar application and no-biochar application). Our preliminary results showed that In all the investigated management, S_{CO2} showed a good correlation with soil temperature but not with soil water content. The highest S_{CO2} (7.6 mmol$CO_2$$m^{-2}s^{-1}$) was measured at the no-till management while the lowest measured S_{CO2} (0.7 mmol$CO_2$$m^{-2}s^{-1}$) was at the conventional management. Regarding biochar management practices the highest S_{CO2} was measured at the conventional management without biochar application while the lowest measured S_{CO2} was on no-till with biochar application. The variances of the random effects determined by a model showed that there was more variance among positions at different management than between measurement campaigns. Furthermore, a mixed-effect model was used to assess the driving ecosystem factors of S_{CO2}. The model shows that no-tillage management has significantly higher S_{CO2} emissions than conventional tillage management. Nevertheless, in our study on maize plantation, the conventional tillage without biochar application management showed a higher averaged S_{CO2} over the whole experiment period, indicating that this kind of soil agricultural management is not appropriate when S_{CO2} is taken into account.

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ICOS Norway – a tool to verify Norwegian emission reduction

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Theme

13. In situ data for climate and other environmental services and policy support

Abstract Text

ICOS-Norway brings together the leading Norwegian institutes for greenhouse gas observations in the three Earth system domains atmosphere, ocean, and terrestrial ecosystems, providing world-leading competence, which is integrated into one jointly operated infrastructure. This provides Norway with a state-of-the-art research infrastructure embedded in European and global efforts. This allows us to provide accurate and accessible data on the Norwegian carbon balance, as well as operate an inverse modelling system to provide integrated top-down assessments at regional scale, across the land, ocean, and atmosphere. ICOS-Norway thus improves our understanding of how greenhouse gas emissions move in the Earth system, and is an essential element in the knowledge base underpinning the Norwegian path towards a net-zero emission society. Here we present the main products provided by ICOS-Norway, as well as future plans.

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A deep learning approach for extracting coal power plant and industrial sector operations using satellite images for GHG and pollutant emissions estimation in India

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

Monitoring facility-level activity for power plants and industrial sites is critical for pollutant and greenhouse gas emission management and mitigating, as well as climate change impacts. India is one of the largest country with coal-powered plants, which contributed approximately 71% of the country's total CO2 emissions in 2021, roughly 1627.306 Mt CO2, according to the International Energy Agency (IEA). Industrial Processes and Product Uses represent 263 Mt CO2 in 2019, mostly drive by cement and steel production.

By harnessing real-time, high-resolution data our approach uniquely merges diverse datasets to deliver unparalleled detail in monitoring emissions at the facility level.We automatically extract coal plant-level activity based on water vapor and smoke plumes detected at individual chimneys or condensation towers from high-resolution satellite imagery (Sentinel-2 and the PLANET constellation), based on deep learning models. The power, cement and steel plants location data is collected from the Global Energy Monitor (GEM). Additional annotations on chimney locations are collected from the Open Street Map. We then validate the extracted activity with energy production reports from the Indian National Power Portal (NPP). Activity detection will be compared with NOx emissions from power plants based on Sentinel-5P TROPOMI data.

Our methodology also seeks to extend its application to the broader industrial sector, including cement and steel plants, or numerous brick kilns across India, a notable source of emissions. This approach creates new datasets for environmental monitoring and detailed temporal emissions profiles of energy and industry sectors emission.

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Characterizing background errors in IFS greenhouse gas emission inversions

Auke Visser[1], Nicolas Bousserez[1], Anna Agusti-Panareda[2], Luca Cantarello[1], Ernest Koffi[1], Panagiotis Kountouris[1], Marc Guevara[3], Thomas Kaminski[4], Ingrid Super[5], Tilman Hohenberger[5], Michael Voßbeck[4], Peter Rayner[4], Marko Scholze[6], Carlos Gomez[6], Richard Engelen[1]

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

The provision of timely and reliable anthropogenic greenhouse gas (GHG) emission estimates is crucial to monitor compliance with emission reduction targets set in international climate agreements. To prepare for a new Copernicus service focused on operational monitoring of anthropogenic GHG emissions (entitled the CO2 Monitoring and Verification Support system, or CO2MVS), the Integrated Forecasting System (IFS) is currently being extended to allow for inverse modelling of CO_2 emissions and co-emitted species (CO, NO_x). A critical step in this development is the definition of the prior error covariance matrix (B matrix) for GHG fluxes, which enables the propagation of information in space, time and across species within this emission inversion system.

In this presentation, we will introduce developments in the IFS B matrix for the CO2MVS and discuss a methodology to derive B matrix parameters (spatial and temporal error correlation scales), focusing on two examples. First, we will show the derivation of B matrix parameters for biogenic CO_2 fluxes (gross primary production and ecosystem respiration), obtained from a pseudo-climatology of residuals between IFS simulations and an observational product upscaled using remote sensing data and machine learning (FLUXCOM). We will highlight the impact of B matrix modifications on derived biogenic fluxes, and show an evaluation based on atmospheric CO_2 observations. Second, we will discuss preliminary results for the derivation of B matrix parameters for anthropogenic emissions, based on an ensemble of global, daily CO_2 emissions obtained by propagating parameter uncertainties in an emission model, and a dataset of cross-species emission error correlations.

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Recent Developments in Satellite and Airborne Remote Sensing of Methane Emissions

Hartmut Boesch, Jakob Borchardt, Heinrich Bovensmann, Michael Buchwitz, John Burrows, Konstantin Gerilowski, Michael Hilker, Sven Krautwurst, Stefan Noël, Max Reuter, Oliver Schneising, Streffen Vanselow

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

The use of satellite remote sensing of methane columns for constraining the global distribution and trends of methane sources and sinks is now well established with more than two decades of satellite observations from SCIAMACHY, GOSAT/-2 and TROPOMI. The impact of satellites has been particular noticeable for regions poorly observed by surface networks such as the Tropics. Satellite observations are also a playing an increasingly important role for identification and quantification of anthropogenic emission sources. TROPOMI data has been successfully used to highlight previously unknown or poorly characterised emission sources thanks to its global mapping capabilities albeit with only km- resolution. This is complemented by observations from a fleet of hyper/multispectral satellite instruments and aircraft imaging instruments that can observe emission plumes with resolutions of tens to hundreds of meters but with limited coverage.

In this presentation, we will give an overview over the IUP-Bremen TROPOMI retrieval of methane and its recent improvements. We will discuss how TROPOMI is used to identify persistent emission sources and to obtain estimates of their emission. TROPOMI observations also provides guidance for detailed aircraft campaigns and targeted observations by high-resolution satellites. As example we will show the recent deployment of the IUP-Bremen aircraft imaging spectrometer MAMAP-2DL to Eastern Australia as part of the UNEP-IMEO Programme to determine methane emissions from coal mining. We will also discuss how we use high-resolution satellite instruments such as PRISMA, ENMAP and EMITS to observe

and quantify methane point source emission and highlight limitations of the retrieval methods.

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Set-up of the first EM27/SUN measurement site in the Po Valley (Italy)

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

The Po Valley is one of the most important economic regions in Italy. Most of the Italian industries are located here and it is also the Italian agricultural heartland. However, due to its peculiar conformation, it is also known as one of the most polluted regions in Europe. Greenhouse Gases (GHG) monitoring in the Po Valley is thus of strategic importance.

GHG can be monitored from ground with both in-situ and remote sensing techniques. In particular, ground-based remote sensing measurements can provide valuable total column datasets for the study of atmospheric phenomena and satellite validation.

In recent years, a network of portable FTIR spectrometers, the COCCON (Collaborative Carbon Column Observing Network), has been developed to complement measurements from high resolution FTIR compliant with TCCON (Total Carbon Column Observing Network) and NDACC (Network for the Detection of Atmospheric Composition Change) networks. The instrument used in the COCCON network is the Bruker EM27/SUN.

In the frame of the EMM project, we recently acquired an EM27/SUN instrument. Here, we show the first results we get from the portable spectrometer located in Bologna (Italy) at CNR-ISAC premises, in the Po Valley, and describe its set-up.

we thank the support of the Next Generation EU funds within the National Recovery and Resilience Plan (PNRR), Mission 4 - Education and Research, Component 2 - From Research to Business (M4C2), Investment Line 3.1 - Strengthening and creation of Research Infrastructures, Project IR0000038 – “Earth Moon Mars (EMM)”. EMM is led by INAF in partnership with ASI and CNR.

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Climate change communication in a time of information abundance

Fran Laurik

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Theme

15. Science communication and outreach to increase the impact of climate research

Abstract Text

Climate change is most likely one of the research fields that both requires and benefits most from science communication. Despite today's information abundance on the topic, it has never been more difficult for a non-expert to differentiate relevant data from political stunts. Funding agencies and society itself are therefore actively demanding for reliable, accessible and understandable communication from researchers.

Despite the sense of urgency, researchers often lack time, expertise and a platform hindering them to communicate to a general audience. Also University of Antwerp (Belgium) faces these challenges. In order to facilitate science communication, three trajectories were developed. First trajectory focuses on the low hanging communication fruits, i.e. participation at science fairs and on site communication. Second trajectory aims for active interaction with local policy organizations. More often than not these organizations face similar challenges researchers aim to tackle. Engaging with policy makers allows to combine research and policy questions and streamline experiments so they can offer benefits on local scale. The third trajectory aims for the integration of climate research in primary and secondary schools. With the startup KlimaatLINK, University of Antwerp established a dedicated climate education project. KlimaatLINK focusses on combining and translating knowledge from state-of-the-art research projects to educational packages that can directly be implemented in the classroom.

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High-Resolution Regional Atmospheric CO2 Inversion: Integrating Data and Models for Carbon Budgets

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Effective mitigation strategies hinge on the accurate assessment of carbon dioxide sources and sinks, the largest greenhouse gas contributing to human-made climate change. Leveraging information from atmospheric concentration observations in combination with inventories and biogeochemical models can provide national-scale estimates of biogenic fluxes and fossil fuel emissions, but current systems do not provide robust estimates over space and time. By integrating the ICOS atmospheric station network within a high-resolution atmospheric model via an inverse approach, we present here a high-resolution inversion system able to quantify CO2 fluxes across continental France, illustrating the methodology and its performances for the year 2022.

Our inversion system aims to optimize CO2 flux estimates at higher spatiotemporal resolutions over France (3km, hourly). The Lagrangian Particle Dispersion Model (LPDM) developed running in backward-in-time model, driven by meteorological inputs from a 3-km run of the Weather Research Forecast Model (WRF), establishes the transport of CO2 molecules. Employing a Bayesian inversion technique, we optimize prior CO2 flux estimates by integrating tower footprints and ICOS atmospheric measurements into a newly-developed inversion framework.

We present the model performance with the evaluation of the inverse flux anomalies for 2022. We assess the capacity of the inversion on leveraging information from atmospheric measurements to enhance our understanding of regional carbon cycling processes, particularly the biogenic component during an intense summer heat wave. We propose to constrain the fluxes by including the incorporation of carbon-14 flask measurements to distinguish fossil emissions from biogenic fluxes and an optimal deployment of ICOS stations.

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Nitrous oxide emissions following organic-based soil amendments in comparison with mineral fertilizer in walnut orchard *(Juglans regia* L.)

Camilla Chieco[1], Daniela Famulari[1], Lorenzo Fiorini[1], Elena Baldi[2], Maurizio Quartieri[2], Lorenzo Brilli[3], Federico Carotenuto[1], Vasileio Voulgaridis[2], Moreno Toselli[2], Marianna Nardino[1]

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Among the non-CO_2 greenhouse gases, nitrous oxide (N_2O) is one of the most important, with the agricultural sectors represents its largest source worldwide. Understanding how different type and amount of fertilizers can determine different N_2O emission patterns and magnitude may help to improve agronomic management in the perspective of both agricultural production optimization (i.e., reduction of N input costs) and climate mitigation (i.e., emissions reduction). In this context, an experimental field campaign to evaluate N_2O emissions from soil based on different type and amount of fertilizers is currently ongoing in a walnut trees (Juglans regia L.) plantation in Bondeno (Emilia Romagna, Italy). Specifically, mineral fertilizer (1) municipal organic waste compost (2), sewage sludge compost from agro-food waste (3), and biochar (4) were tested. Soil amendments were added at the beginning of the season within the row, while mineral fertilizer was added twice 30 days apart. Soil N2O fluxes were measured using a portable N_2O trace gas analyzer (LI-7820 N2O /H2O, Li-Cor) connected with an automated soil chamber (LI-8200-01S Smart Chamber, Li-Cor) along the whole growing season. Furthermore, monthly data of soil TKN, mineral N (NH_4^+ and NO_3-) and moisture were also measured. Despite the experiment is still running, preliminary results suggested as different fertilization treatments provided differences in magnitude of cumulated soil N_2O emissions.

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Limitations on the accuracy of point-source emission estimation due to atmospheric turbulence

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

Monitoring of greenhouse gas emissions is a critical part of climate mitigation. Without timely, accurate and precise information on the policy implementation status, potential diversions from the plan cannot be identified and acted upon in time. Emission estimation methods based on direct space- or airborne observations hold much promise for the provision of relevant data across policy-relevant scales, especially when applied to the strongest sources of greenhouse gases, like coal power plants, megacities or industrial sites.

Using the high-resolution WRF-GHG framework set over the largest point-like CO_2 emitter in Europe, we demonstrate how atmospheric turbulence affects the plume structure, limiting the accuracy of estimated emissions using the cross-sectional mass-flux method. Through a novel application of temporally-tagged tracers, we show that the apparent CO_2 emission variability is due to turbulence at the point of emission and then propagated across distances significantly longer than PBL turbulent scales.

Unless the discussed effects can be taken into account when planning, executing and interpreting measurements, they will have detrimental consequences for emission monitoring. It is worth noting that the presented results are of general nature and will affect attempts to quantify emissions of any pollutant for which similar estimation techniques are applied, including CO_2, CH_4, NO_x and others.

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A paired flux tower-dendrometer network to investigate forest carbon from assimilation to allocation to tree growth

Mukund Rao[1], Troy Magney[2], Ivan Janssens[3], Josep Peñuelas[1]

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Carbon assimilated through photosynthesis is distributed among various plant processes with only a fraction allocated to tree secondary growth. This woody biomass constitutes a long-term carbon pool on the landscape. The allocation of carbon to tree growth, respiration, and reproduction is not constant but highly dynamic. Understanding the post-assimilation dynamics of carbon, particularly its allocation to tree growth, is crucial to comprehending the potential of forests as long-term carbon sinks. To address this, we propose the utilization of dendrometers, which are sensors mounted on tree trunks and capable of monitoring micrometer-scale changes in tree radius due to growth and hydration. In this presentation, we introduce a collaborative paired flux-tower dendrometer network comprising 20 locations across 14 countries, encompassing tropical sites in Costa Rica and Mexico, as well as temperate and boreal sites in Europe and North America. At each site, tree dendrometers are co-located within the footprint of eddy covariance tower-based ecosystem carbon fluxes and tower-based remote sensing measurements (e.g. PhenoCams, hyperspectral and SIF). We will share preliminary results from diverse ecosystems, focusing on the timing and manner in which forests assimilate carbon through photosynthesis, allocate it to above-ground growth, thus creating a long-term carbon sink, and elucidate the influence of climate and water availability on these processes. As ICOS formalises its plans to install dendrometers across all forested sies, we extend an invitation to community members who currently have or wish to establish paired flux towers and dendrometers at their sites to join, collaborate, and contribute to this synthesis.

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Understanding High Arctic Tundra vegetation dynamics: Insights from a multi-year study on carbon fluxes and carbon isotope composition

Carlotta Volterrani[1,2], Olga Gavrichkova[1,3], Emanuele Pallozzi[4,3], Enrico Brugnoli[1], Angela Augusti[1]

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

Arctic terrestrial ecosystems undergo serious alterations due to climate change, with both arctic greening and browning being reported as potential response trends. In order to improve knowledge on high arctic tundra vegetation dynamics and evaluate its consequences for the C balance, *Dryas octopetala* and *Salix polaris* were considered during 3 years of measurements, being among the most abundant and representative species in Svalbard Islands. Experimental design was based on measurements of CO_2 fluxes - ecosystem respiration (R_{eco}), gross primary production (GPP) and net ecosystem exchange (NEE) - environmental parameters (soil temperature, moisture, photosynthetically active radiation (PAR)) and plant stable isotope composition ($\delta^{13}C$). A common response patterns for C fluxes, could be highlighted across years, for both species. They were acting as C sink, which strength grew across years. Moreover, leaf $\delta^{13}C$ showed a more negative value for *D. octopetala* compared to *S. Polaris* (-30,48‰ versus -28,71‰, respectively, as 3-years-avarage). NEE was most sensitive to PAR variation rather than to temperature and soil humidity changes. R_{eco} instead increased with soil temperature and correlated with vegetation $\delta^{13}C$ highlighting substantial impact of vegetation to this flux. Changes in cloudiness and soil temperature will be the primary factors affecting the C balance of high arctic tundra communities, although the impact of plant species dynamics should be considered.

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Bottom-up evaluation of greenhouse gases (CO_2, CH_4, N_2O) at regional scale

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Comprehensive budget evaluations of greenhouse gases (CO_2, CH_4, N_2O) are unequivocally important for the accomplishment of the mitigation goal of the Paris Agreement. In addition to atmospheric monitoring using satellite-to-ground platforms (top-down), independent assessment using a bottom-up approach, which aggregates ground-level sinks and sources, is necessary to give an independent validation. This study demonstrates a bottom-up evaluation system of greenhouse gas budgets at the country to global scales, which is developed for the Environmental Research Fund "S-22: Comprehensive Study and Monitoring of Long-lived Greenhouse Gases and Short-lived Climate Forcers toward Mitigation of Climate Change", funded by the Ministry of the Environment, Japan. For each gas, natural and anthropogenic greenhouse gas sources and sinks are evaluated using geographic data, emission inventories (e.g., EDGAR), biogeochemical models (e.g., VISIT), and satellite products (e.g., GFED). For example, total CO_2 budget is evaluated for net ecosystem production (photosynthesis – respiration) of natural ecosystems, land-use emissions, wildfire, fossil fuel mining, industrial and municipal sectors, waste management, and agricultural sectors. The method was successfully applied to the CH_4 budget of Asia region (Ito et al., 2023, 10.1029/2023GB007723) and to the N_2O budget (Ito and Nishina, submitted). The method clarifies spatial distribution and temporal variation of individual and combined sources and sinks, enabling us to specify emission hot spots and remarkable sectors for the mitigation target. This presentation shows the results of the Asian greenhouse gas budget during 1970–2022 using the updated bottom-up approach.

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Complex spatial and temporal patterns of greenhouse gas emissions central London, UK: hotspots and long-term trends.

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

We report on over a decade of measurements of greenhouse gas (GHG) fluxes from a tall tower in central London, UK. Measurements of carbon dioxide (CO_2) and methane (CH_4) by eddy-covariance from atop the 190 m BT Tower (51°31’17.4 N, 0°8’20.04 W) began in late 2011; nitrous oxide (N_2O), carbon monoxide (CO), nitrogen dioxide (NO_2) and ethane (C_2H_6) have been measured since 2021. Land-use is very diverse within the flux footprint of the tower, with a juxtaposition of commercial and residential areas, transport hubs as well as extensive green spaces. This results in spatially heterogenous activity levels with distinct temporal dynamics, which modulate the fluxes at timescales ranging from hourly to inter-seasonal.

The measured CO_2 (2012-2019 mean +/- standard deviation: 41.0 +/- 2.4 kton.km^{-2}.y^{-1}) budget validates the bottom-up estimates from the London Atmospheric Emissions Inventory (LAEI; 38.7 kton.km^{-2}.y^{-1} for CO_2), demonstrating that urban sources of this gas are well known. In contrast, our measurements reveal that CH_4 emissions are underestimated by ca. a factor of 2 (measured: 69.9 +/- 3.3 ton.km^{-2}.y^{-1}; LAEI: 29.0 ton.km^{-2}.y^{-1}). We attribute this discrepancy in part to an underestimation by the inventory of leaks in the natural gas distribution network, but observed hotspots of CH_4 in areas of low C_2H_6 (a tracer for fossil fuel CH_4 emissions) fluxes could indicate emissions of biogenic origin. Finally, despite a decrease in emissions in 2020 and 2021 due to Covid-19 restrictions and the introduction of an ultra-low emissions zone in 2019, we observed little inter-annual variability in CO_2 and CH_4.

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Mapping CO_2 fluxes of drained fen meadows in the Netherlands with machine learning

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

In the Netherlands, emissions from drained organic soils amount to around 3% of all national greenhouse gas emissions. Following the 2019 mitigation target, the Netherlands Research Progamme on Greenhouse gas dynamics in Peatlands and organic soils (NOBV) investigates the efficiency of proposed mitigation measures, and aims to enhance the understanding and quantification of drivers of regional peatland emissions. Our study is in line with NOBV's objectives and aims to provide regional CO_2 balances for the three main fen meadow areas in the Netherlands.

As part of the NOBV campaigns, Eddy Covariance (EC) measurements are taken from a low-flying aircraft since 2020. Additionally, a large EC tower network has been established with both stationary and mobile systems, encompassing 25 measurement sites.

In this study, we combine airborne and tower CO_2 flux data, to make use of their different strengths: spatial heterogeneity and temporal continuity, respectively. We use footprint analysis to extract the corresponding spatial information from maps, remote sensing, and outputs of several soil and water models. Using this data, we train a boosted regression tree (BRT) machine learning algorithm. Feature selection and hyperparameter tuning are applied as model optimization techniques, and subsequently Shapley values are used to interpret the model's outputs. We will present the found relationships with e.g. groundwater level, as well as high resolution modelled CO_2 flux maps from which we estimate daily, monthly and yearly CO_2 balances.

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Eddy covariance GHG fluxes from grasslands on mineral and drained organic soils in eastern Finland

Narasinha Shurpali[1], Olli Peltola[2], Tero Toivonen[1], Samuli Launiainen[2], Janne Rinne[2], Mikko Järvinen[1], Perttu Virkajärvi[1]

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

Finland, with a predominantly boreal climate, is known for its milk production with an average yield of 8888 kg per cow in 2022. Grass-based production could be the key to sustainable milk and beef production. In Finland, grass is the main feed for milk and beef cattle. As a perennial plant, grass is almost the only crop plant that has the potential of preserving soil carbon. Milk and beef production are tightly connected, and nearly 80% of the Finnish beef production originates from the milk chain. The Finnish soils can be roughly categorized into two categories: mineral and organic soils. Mineral soils are typically well-drained and have a low organic matter content, whereas organic soils are characterized by high organic matter content and high-water retention capacity and these differences have a pivotal role in ecosystem-atmosphere greenhouse gas (GHG) exchange. With this in view, the Natural Research Institute Finland has initiated a long-term GHG flux monitoring framework for a sustainable grassland management and agriculture across several agricultural research clusters in Finland. Continuous data on GHG fluxes from managed grasslands on different soil types are being collected using the eddy covariance technique since 2020. Here, we present seasonal and annual variability in GHG fluxes and their short-term responses on management and environmental variability from three grassland sites in eastern Finland during two complete study years (2022 and 2023).

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X-ray CT scanning for intra-seasonal tree biomass assessment: potential application for carbon allocation in forests

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Recent studies have questioned the general assumption of a strict correlation between seasonal wood growth vs. diameter the temporal decoupling of cell enlargement and cell wall thickening. However, studying these formerly named growth phases has proven to be challenging due to technical limitations especially for angiosperms.

A new cutting edge technique (Lehnebach et al., 2021), High-resolution X-ray Computed Tomography (XµCT), has proven to enhance accurate estimating of relevant tree xylogenesis parameters in a range of tree species, wood anatomies and wood structures. In addition it, also enhances the of quantification of intra-annual biomass production dynamics was proven by Lehnebach et al. (2021).

Seasonality of carbon uptake and biomass growth since carbon makes up a large part of biomass building blocks. Hence the potential of using XµCT to perform detailed studies on carbon allocation in trees and forest ecosystems. There is a direct link between XµCT-date and the density of scanned material. Seasonal stem circumference data and seasonal carbon fluxes can be assessed in parallel to seasonal stem biomass production based on XµCT-data.

There is a great potential to disentangle the incorrectly assumed correlation between seasonality of wood growth (and C sequestration (GPP/NPP)) vs. seasonality of diameter increase with the knowledge gaps that will hopefully be filled using these new methodologies.

After initial results have been verified a study across several ICOS sites will be setup to further investigate the effects of tree species, climatic conditions and forest management on carbon allocation in forests.

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Monitoring a pine stand by means of automated drone surveys

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Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

In an upcoming project, the ICOS Class 1 forest station of Brasschaat (BE-Bra) will be monitored on a semi-continuous basis by means of automated drone surveys. A drone is being custom build for this purpose and will be equipped with a SIF sensor, a thermal camera and multiple hyperspectral cameras. The drone will carry out repeated, automated flights over the pine stand throughout the entire growing season. The data collected with the drone will be used for quantifying stand productivity, monitoring tree health, ground truthing of satellite data, and evaluating measurements from the fixed eddy covariance tower. At the time of writing this abstract, the drone is not yet operational. Test flights are expected to take place in the second half of 2024 and routine flights are expected to start at the beginning of the 2025 growing season.

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Cyprus Atmospheric Observatory: Insights into Greenhouse Gas Monitoring in the Eastern Mediterranean and Middle East

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Cyprus, an island located in the Eastern Mediterranean and Middle East (EMME) region, stands as a natural laboratory for studying local and regional pollution characteristics, due to its proximity to three continents: Europe, Asia, and Africa. This is particularly important given that increasing anthropogenic greenhouse gas (GHG) emissions over the last decades in the EMME region, led to regional warming at a rate twice that of the global average.

In response to the imperativeness of monitoring GHG' spatial and temporal variability, the Cyprus Atmospheric Observatory inaugurated a GHG station in Ineia (INE), within the remote and natural Akamas peninsula located on the western coast of the island. INE aims to be integrated into the ICOS atmosphere network as a class 2 station. Analysis of air masses origin conducted with the Lagrangian FLEXPART model, denoted the predominant influence of the Eastern Mediterranean Sea, complemented by contributions from Turkey and Europe, with additional influences from Middle East and Africa, subject to seasonal shifts in wind patterns. The INE quartiles (Q1, Q2, and Q3) of the last year for CO2, CO, and CH4 are respectively: [418.5, 423, 426], [112.6, 123, 136] and [1988.5, 2002, and 2014]. Our measurements are compared with other GHG monitoring stations in the region, such as Finokalia and Lampedusa.

Across the island, various ICOS class instruments conduct short-term, campaign-based, and long-term measurements of GHG. Additionally, ongoing since 2019, long-term total-column GHG observations (XGHG) from the TCCON Nicosia serve as a satellite and model validation site.

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Assessing the variations of Atmospheric Methane concentration across the state of Gujarat, India during 2020-22 using satellite data

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Methane is a potent green house gas that has a warming potential far higher than Carbon dioxide. Despite its high warming potential compared to carbon dioxide, methane emissions, particularly from urban areas worldwide, are poorly understood. To partially address this gap, the present study utilizes a space-based remote sensing approach, employing data from the TROPOMI instrument aboard the Sentinel-5 precursor satellite. Over a three-year period from January 2020 to December 2022, the study assessed atmospheric methane concentrations across the state of Gujarat which is the 5th largest Indian state having a geographical area of 196,000 km^2.

Findings reveal an average annual concentration increase of 0.69% during this period. Specifically, methane levels rose by 4.1 parts per billion (ppb) from 2020 to 2021 and by 21.9 ppb from 2021 to 2022. In 2021, methane levels increased in 77.1% of Gujarat, ranging from 0-20 ppb, while decreasing in the remaining 22.9%. However, in 2022, levels increased across the state, predominantly ranging from 10-35 ppb compared to 2021.Notably, the Dang district consistently exhibited the lowest methane concentration, attributed to its dense forest cover. Conversely, central Gujarat, including districts like Ahmedabad, Gandhinagar, Patan, and Kheda, displayed the highest concentrations. Junagadh, Botad, and Anand districts showed the highest annual increase rates. Overall, these findings are crucial for informing and enhancing the Methane Emissions Reduction Action Plan in Gujarat, aiding in climate change mitigation efforts.

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Groundwater level control as GHG emission reduction option tested using eddy covariance for peatland in the Netherlands

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Theme

14. Leveraging Direct Flux Measurements Beyond Academia for Real-World Applications

Abstract Text

In this work, the annual CO_2 and N_2O balance and analysis of the drivers for fertilized grassland on peat for a dairy farm under three groundwater level control options will be presented.

This experiment is conducted in the context of the Dutch NOBV project (National Research program on GHG for peatland areas) as part of the Dutch Climate Agreement which has a chapter to reduce GHG emissions from peatland areas by 1 $MtCO_2$-eq annually.

The groundwater level control options applied are the conventional ditch water level control system, nowadays often being replaced by drainage and ditch level control, and finally drainage and pressure control. Several fields of the Zegveld experimental farm are divided in three segments each which a control option applied and a such allow study under comparable conditions.

The GHG fluxes reported are measured in parallel using one closed-path Aerodyne system switching inlet line each half hour using three small towers equipped with a Gill sonic anemometer at 1.75 m height in the middle of the largest elongated farm field. The location and low measurement height maximize the representation of the field in the flux measured from all wind directions. Flux loss tests and corrections, both using ogive analysis and comparison with an open-path CO_2 system installed at one location, as well as gap-filling methods are applied.

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Strategy developed at the Regional Space Observatory to monitor carbon budget components on cropland in southwestern France

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

A coherent database is essential for the development, calibration, and validation of methods allowing to monitor the effect of carbon farming practices on SOC stock changes and carbon budget components (biomass, yield, CO_2 fluxes). As a pilot site for the launch of Sentinel satellite missions, our predominantly agricultural study region in south-western France has regular long-term monitoring of carbon-related variables. The database combines in situ measurements (on two agricultural plots, flux towers and meteorological stations ensure since 2005 continuous acquisition of CO_2, water and energy fluxes) and optical satellite images (acquisitions by Formosat-2, Spot-2/4/5, Landsat-5/8 and Sentinel-2), together with data and/or information on farming practices collected from various partners. This presentation provides an overview of the experimental carbon monitoring systems implemented as part of the RSO SO (Regional Space Observatory Sud-Ouest).

The transposition of the approaches developed on the study site on regions with contrasting conditions would increase the impact of the research work. The provision of comparable databases (via a device such as the Environmental Information System on our study site) on networks such as ICOS is an opportunity to study the transposability of the proposed models (Pique et al. 2000a, Pique et al. 2000b, Wijmer et al. 2023).

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Contribution of soil organic carbon variations to the carbon footprint of a farm

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Theme

13. In situ data for climate and other environmental services and policy support

Abstract Text

Agricultural systems are confronted with the dual challenge of meeting the nutritional need of the population while mitigating their environmental impacts. Livestock production, responsible for 13% of global greenhouse gas (GHG) emissions, contributes to methane emissions from enteric fermentation and manure management, and nitrous oxide emissions from nitrogenous fertilizers application.

Increasing soil organic carbon (SOC) content in farms 'grasslands and croplands has been suggested as a strategy to mitigate the carbon footprint of livestock production. However, there is currently a lack of consensus on how to effectively include SOC variation into carbon footprint assessment methods, such as Life Cycle Assessment (LCA).

This study conducts an LCA of a crop-livestock farm located in southern Wallonia, Belgium, to estimate the carbon footprint of the entire farm's production in 2021. Furthermore, the study assesses the range of SOC variation in farm's grasslands and croplands by combining data from successive regional SOC inventories and flux approach on two ICOS stations, located in the farm (for grasslands) or nearby (for croplands).

The results reveal that the carbon footprint of the farm's animal production in 2021 amounted to 10,2 kg of CO2-equivalent per kg of liveweight. Furthermore, SOC variation ranges from potentially augmenting this footprint by 2% to offsetting it by -22%, depending on the methodology used for SOC calculation.

This research highlights the complexities associated with integrating SOC variation into agricultural LCAs and emphasizes the need for further investigation in this area.

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High uncertainty in ocean afforestation efficiency due to stoichiometric variability and iron limitation

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Theme

8. Enhancing the ocean carbon sink: the science, verification, and governance of marine-based carbon dioxide removal (mCDR)

Abstract Text

Carbon dioxide removal (CDR) has emerged as a crucial component of climate change mitigation strategies. Among the various CDR approaches, ocean afforestation via macroalgae cultivation shows promise due to its high productivity and carbon-to-nutrient ratio. Macroalgae cultivation shifts production from phytoplankton to macroalgae. The CDR efficiency is closely related to the comparative ability of macroalgae and phytoplankton to fix carbon with a given nutrient pool according to their stoichiometry. The carbon-to-nitrogen (C:N) and carbon-to-phosphorus (C:P) ratios in seaweed tissue exhibit significant variability, influenced by environmental factors. However, current modeling efforts have overlooked the variability of stoichiometry, as well as the critical role of iron limitation and consumption by macroalgae.

Using the NEMO-PISCES ocean biogeochemical model, we explore the spectrum of stoichiometric variability observed in macroalgae, along with a range of half-saturation constants. Under a prescribed macroalgal production rate of 0.5 PgC yr^{-1}, stoichiometry is found to be the primary driver of CDR efficiency, with efficiencies ranging from -50% to 91%. Notably, the largest uncertainty is introduced by C:P ratio variability.

In terms of global production potential, both stoichiometry and half-saturation constants are equally important, with iron being the most critical element. Furthermore, the iron consumption and limitation reduce macroalgal production potential by up to eightfold and CDR efficiency by 17% globally. This result underscores the need to consider this dependency in discussions surrounding afforestation strategies.

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From forest to atmosphere: towards a more comprehensive assessment of BVOC exchanges in a mixed temperate forest

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Theme

2. Exchange of reactive gases and aerosols between the land surface and the atmosphere in natural and managed ecosystems

Abstract Text

Forests are the primary global source of biogenic volatile organic compounds (BVOCs), pivotal in atmospheric chemistry. While emissions of isoprene and monoterpenes, the most emitted BVOCs at the global scale, are generally well-estimated, uncertainties persist regarding the diversity, magnitude, and temporal variability of other BVOC exchanges that impact the non-methane volatile organic compound (NMVOC) budget and atmospheric chemistry.

To address this, half-hourly net BVOC fluxes were measured at the Vielsalm ICOS station, a Belgian mixed temperate forest, during spring-autumn 2023, using a PTR-TOF-MS instrument (PTR-TOF-4000, Ionicon Analytik GmbH) and eddy covariance. In total, 33 VOC-related m/z values showed significant emissions or depositions.

Throughout the campaign, the net BVOC exchanges are positive, with the top 10 BVOCs accounting for 90% of observed BVOC emissions (in mass balance), led by monoterpenes, isoprene, and methanol. Isoprenoids and their derivates were emitted consistently, influenced by air temperature and solar radiation. Conversely, lighter oxygenated BVOCs like alcohols, organic acids, and aldehydes exhibited bidirectional net fluxes, sometimes favouring deposition, especially in lower photochemical and higher humidity conditions.

To investigate their impact on atmospheric reactivity, fluxes were multiplied by their corresponding reaction rate constants with OH radicals. Isoprene and monoterpenes were found to account for 70% and 22% of the total OH reactivity flux, respectively.

Further analysis will focus on bi-directional exchanges of VOCs between the forest canopy and the atmosphere. For this, we will start by comparing our results with existing emission models (e.g., MEGAN) and focus on deposition occurring in the canopy.

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Quantification of carbon dioxide and methane emissions from a Chinese city based on eddy covariance measurements

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Accurate quantification of greenhouse gas (GHG) emissions from cities is essential to support the local climate change mitigation actions. Eddy covariance (EC) technique provides the most direct and reliable data for estimating GHG emissions at local scale. So far, most GHG EC studies in urban area were reported in Europe and the United States. However, only a very limited number of reports are from China. Here, we present EC flux measurements of CO_2 and CH_4 in the urban area of Ningbo, a city in the eastern China with a population of near 4 million in its central urban area. Since the December of 2022, CO_2 and CH_4 fluxes have been simultaneously measured at 100 m height on a 140 m tall TV/radio transmitter tower in the city center. This is the first long-term EC flux dataset of both CO_2 and CH_4 from a Chinese city. The results show that the city was a net source of CO_2 and CH_4 during all seasons. The CO_2 flux of Ningbo was lower than most European cities and the CH_4 flux was lower than London and Florence. Significant increase in both CO_2 and CH_4 emissions were observed after the lift of COVID lockdown. In this presentation, we will discuss the temporal and spatial patterns of CO_2 and CH_4 fluxes, as well as comparison with inventory estimates. Such long-term EC measurements in Chinses cities are significant in the context of national policy of “coal-to-gas” and the increasing popularity of electric vehicles in China.

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SCOUT: Street-Level Carbon Observatory for Urban Terrain

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

City governments worldwide are implementing climate protection strategies to reduce carbon emissions and adapt to the ever-increasing challenges of climate change. Measurement, Reporting, and Verification (MRV) capabilities are vital in guiding these efforts, aiding in developing targeted strategies, tracking their progress, and assessing the outcome. Utilizing urban atmospheric CO_2 measurements to inform climate action plans provides vital information on direct carbon emissions and their spatial and temporal variability.

We introduce a street-level CO_2 sensor network comprising 100 commercially available, battery-powered, low-cost nodes installed on lamp posts across Munich. The sensors are strategically positioned at locations with different emission characteristics and partly co-located with air quality sensors, traffic detectors, and more precise CO_2 sensors to assess data correlations and quality.

An accuracy improvement of factor 3 to 10 compared to the manufacturer's accuracy (50 ppm) was achieved with our bias correction algorithm and individually trained sensor models. Each device includes additional temperature, humidity, and atmospheric pressure sensors that were used as predictors for machine learning algorithms. Additionally, we upgraded the systems with solar radiation shields to mitigate radiative heating effects and reduce temperature-induced sensor errors. Our sensor characterization process includes over four months of reference measurements using a PICARRO G2301 analyzer across three seasons. Furthermore, we performed climate chamber experiments following defined temperature, humidity, and CO_2 concentration protocols.

We will share insights from network operations, introduce our newly developed, automated data processing pipeline, and discuss initial findings and learnings gleaned from the sensor data.

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Demonstrating atmospheric O_2/N_2 measurements as a proxy for fossil fuel CO_2 in the city of Heidelberg, Germany

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

The ability to isolate the fossil fuel CO_2 (ffCO_2) component of total atmospheric CO_2 is a crucial part of top-down atmospheric ffCO_2 verification efforts, owing to large non-fossil fluxes of CO_2 in and out of the terrestrial biosphere. Atmospheric measurements of radiocarbon ($^{14}CO_2$) are the gold standard for this purpose, but the availability of such data is currently limited due to its high cost. Furthermore, continuous radiocarbon measurement capability, while promising, is not yet available with sufficient precision.

Here, we present an alternative observational approach for separating ffCO_2 and non-fossil CO_2 using continuous atmospheric measurements of O_2/N_2 and CO_2 from the city of Heidelberg in Germany. The continuous O_2/N_2 and CO_2 data are combined into the quantity “Atmospheric Potential Oxygen” (APO), a tracer that (by design) is invariant to CO_2 and O_2 fluxes from/to the terrestrial biosphere. We demonstrate that APO can be used as a continuously measurable proxy for ffCO_2 in Heidelberg by comparing to $^{14}CO_2$-based estimates of ffCO_2 from over 500 flask samples, which were collected over a period of two and a half years from 2018-2021. We examine the variability in APO:ffCO_2 ratios and quantify APO-based ffCO_2 uncertainties during different seasons.

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SOOP - Shaping an Ocean of Possibilities: Improving Ocean Observations through Science-Industry Collaboration

Tobias Steinhoff[1], Toste Tanhua[1], Sören Krägefsky[2], Klas Ove Möller[3]

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Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

Vast parts of the ocean are not monitored at all and are widely unknown, and there is a significant need for more fit-for-purpose in-situ observations. At present, ocean observation systems are a bespoke market where standardisation and economies of scale are not always achievable. Here, we present the recently funded innovation platform of the German Helmholtz Association “Shaping an Ocean of Possibilities for science-industry collaboration (SOOP)”. We are going to harness the curiosity and creativity of our partners to sample essential ocean and climate variables including ocean carbon at unprecedented scales. SOOP aims to bring users, developers and manufacturers of sensors together around a set of key innovative projects. SOOP thus provides a platform of cooperation between industry, science and civil society to jointly build competencies and growth of ocean observations and technology. SOOP supports the growth of the “New Blue Economy” sector by actively enhancing the bi-directional knowledge and technology transfer between science and industry.

We will present ongoing projects concentrating on marine carbon observations and a variety of platforms. The SOOP platform will grow (in terms of partners and EOVs) based on the experiences from diverse pilot projects. These projects are aimed at developing ocean observation equipment based on common protocols that can be fitted to a whole range of platforms, ranging from recreational vessels to global container fleets. SOOP aims to activate non-scientists to scale-up science-grade ocean observations for a more sustainable use of our oceans.

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Locating the signal: mapping the carbon landscape of European cities to inform urban emission monitoring strategies

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Imagine a city in Europe. Does it have lots of parks and vegetation, or are its streets busy and filled with cars? Do you see plumes coming from chimneys of heavy industry or a coal-fired power plant? In this study, we collect such characteristics to improve our understanding of the so-called “carbon landscape” of 308 European cities. Understanding this landscape can guide decisions on emission mitigation and monitoring. Common traits across clusters of cities help identify the most effective monitoring strategies for each cluster. Our study collects, selects, clusters, and interprets these 308 carbon landscapes, and the resulting data and maps are made publicly available at the ICOS Carbon Portal.

We will demonstrate the power of our clustering approach by showing how city-wide emissions compare to the net biogenic drawdown and how this helps us define a monitoring measurement strategy. In many of the cities, during summer daytime hours, the biogenic CO2 uptake exceeds fossil fuel emissions by a factor of 10. This indicates that measurements should be focused during winter when the emission signal is stronger. However, during winter daytime hours, the biosphere generally becomes a net source of carbon, contributing a significant (>30%) share to the carbon budget in half of the cities. Thus, these cities would benefit from a monitoring strategy that helps separate the biospheric component from fossil fuel emissions, using methods such as co-emitted species detection or radiocarbon analysis.

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Gas exchange patterns of CAM plant *Agave sisalana* and photosynthetic plasticity as environmental response measured by eddy covariance

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

The Crassulacean acid metabolism (CAM) is a special adaptation to dry conditions that enables plants to take up carbon during night. Only few studies assessed the gas exchange of CAM plants at the ecosystem level. Here, we measured the net CO_2 exchange of the CAM plant *Agave sisalana* using the eddy-covariance method in an agricultural field in semi-arid Kenya. Our measurements spanned 65 days and started in a wet period that gradually turned into a dry period. We observed high productivity of *A. sisalana* during the wet period which was linked to significant day- and nighttime carbon uptake, suggesting direct CO_2 fixation via the C3 pathway during daytime. In the dry period, daytime net CO_2 exchange switched from carbon uptake to carbon release, suggesting a shift towards strict CAM photosynthesis in response to drier soils. Our results show the high photosynthetic plasticity of *Agave sisalana* in response to soil drying and its importance for the net CO_2 exchange at the ecosystem level.

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Feedback between climate, land-atmosphere fluxes and structure in a forest ecosystem severely damaged by recent hot-droughts

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

Re-occurring dry and hot summers with high irradiance have caused irreversible damages in forest ecosystems across Central Europe, including the ICOS ecosystem associate site Hartheim (DE-Har). The site experienced irreversible damages to a Scots pine (*Pinus sylvestris*) plantation with a mortality of >50% of all *P. sylvestris* trees following the 2018 drought. Dead and fallen trees were generally not removed in the area surrounding the site. In the last 6 years, DE-Har has undergone a significant regime change in which increased light under the damaged/missing tree crowns has accelerated growth of deciduous understory trees. We use eddy covariance measurements from pre- and post-drought periods and combine them with ecophysiological measurements at the individual tree level to estimate effects on long-term carbon, energy and water fluxes. We find that CO_2 uptake in summer is only about 40% of pre-drought uptake and that in the period 2019-2023 the site became an annual net carbon source, whereas 15 years ago the forest was a considerable CO_2 sink. Ecophysiological measurements show that understory trees have higher transpiration and ecophysiological activity compared to the previously dominant *P. sylvestris* canopy. On a decadal scale, annual transpiration decreased, most notably in winter, and the seasonality of fluxes was intensified, as can be seen on remote sensing products related to canopy greenness such as satellite-based vegetation indices and phenocams. The observed changes altogether provide information on how forests that reached tipping points transition functionally and structurally and how this affects interactions between land and atmosphere.

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Application of in situ CO2 and CH4 concentrations measurements on-board UAV to monitor surface emissions on a grazed grassland, against ground-based Eddy Covariance

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Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

An open-path laser absorption spectrometer has been developed to measure in situ CO_2 and CH_4 concentrations on-board Uncrewed Aircraft Vehicles (UAV). Associated with a mass balance model, it proved suitable to detect and quantify point-source emissions with fluxes down to 0.01 g/s in industrial contexts (Bonne et al., AMTD, 2023). New developments were conducted on the instrument, including a newly embarked 2D ultrasonic anemometer, together with sensitivity and stability improvements.

To explore potential new applications of this instrument to diffuse surface emissions with low concentrations enhancements and benchmark it against an already established Eddy-Covariance flux tower, a monitoring campaign has been conducted in 2024 on the grazed grassland at the FR-Mej (Méjusseaume) flux tower site.

The site is an ICOS-Ecosystems associated station over intensively managed grazed grassland, part of the INRAE-IEPL dairy experimental farm (180 dairy cows and 170 dairy goats) situated in NW France. The field is grazed by dairy cattle 4 to 6 times yearly, with a livestock density between 20 and 60 LSU/ha during grazing phases. Methane surface fluxes are monitored using the eddy covariance technique, with wind and turbulence measured by a Gill HS50 3-D ultrasonic anemometer and CH_4 mixing ratios measured at 10 Hz by a MIRO MGA quantum cascade laser analyser. Half-hourly fluxes were derived using the Eddypro software.

This experiment is part of an effort to apply these UAV-based measurement to various types of natural or anthropogenic sources including bogland or agricultural biogas digesters.

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A new open-path CH_4/H_2O analyzer for eddy covariance CH_4 flux measurements with minimal temperature-related spectroscopic corrections

Wenru Yang[1], Huancheng Zhang[1], Kai Wang[2], Ting-Jung Lin[3], Xunhua Zheng[2], Yin Wang[1]

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Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

Eddy covariance (EC) flux measurement based on open-path laser spectroscopic gas analyzers is widely used for CH_4 flux measurements, but current commercial analyzers are subject to significant spectroscopic corrections for the in-situ temperature fluctuations, leading to large uncertainties in the measured background CH_4 fluxes. The modified Webb-Pearman-Leuning (WPL) approach was introduced to help reduce errors in open-path or temperature/pressure-uncontrolled flux measurements due to spectroscopic effects.

This work presents an open-path CH_4/H_2O dual-component laser analyzer (Model: HT8600-Plus, HealthyPhoton Co., Ltd.) suitable for future EC CH_4 flux measurements with minimal temperature-related flux corrections. HT8600-Plus utilizes an interband cascade laser (ICL) to simultaneously probe the mid-infrared transitions of CH_4 at ~3221 nm and H_2O at ~3223 nm. The CH_4 absorption line was selected by considering spectroscopic effects that counteract density changes resulting from temperature fluctuations, thereby nearly mitigating the combined impact of density and spectroscopic effects.

Field experiments are performed to compare fluxes measured from a single HT8600-Plus instrument against fluxes measured from a two-unit system with a commercial open-path CH_4 analyzer and an NDIR CO_2/H_2O analyzer. Preliminary results showed that raw fluxes from HT8600-Plus achieved high consistency with the modified-WPL corrected fluxes from the commercial analyzers, indicating its versatility for field CH_4 flux monitoring and the low temperature-related flux corrections as proposed.

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Investigating high-latitude carbon cycle response using an EC-Earth framework

Rayanne Vitali[1], Peter Langen[1], Anna Rutgersson[2], Erik Jan Schaffernicht[2], Lichuan Wu[2], Minchao Wu[2,3]

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

High latitude and Arctic regions are critical in understanding climate change dynamics: harbouring critical tipping points, storing vast carbon stocks, and experiencing accelerated warming rates surpassing those of any other region on the planet. However, the complexities of Arctic processes pose significant challenges for accurate prediction. Projections of changes in the Arctic regions have low confidence, primarily due to uncertainties associated with modeling multiple interacting drivers and ecosystem responses. Thus, enhancing our understanding of high latitude processes, their interactions, and associated feedbacks is crucial for comprehending the global response to future climate change.

Work presented here forms part of the GreenFeedBack project and aims to assess the strengths of high latitude terrestrial, freshwater and ocean processes, interactions, and their associated feedback using an Earth System Modelling framework. Using results from fieldwork and modelling studies, we implement changes to high latitudes into the EC-Earth model before conducting a series of sensitivity simulations spanning historic, present, and future scenarios. Simulations are then complimented by a budgeting framework, facilitating the assessment of greenhouse gas fluxes, and allowing an assessment of the different high latitude processes through a flux box model.

While still in its early stages, this study demonstrates the potential of our framework methodology. Preliminary results showcase how our approach can illuminate key processes governing Arctic carbon cycle response and feedback under climate warming. By refining our understanding of high latitude dynamics, we aim to contribute to more accurate climate change predictions and mitigation strategies.

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A new ICOS Class 1 station at CNR-IMAA: starting a new infrastructure in the hearth of Mediterranean basin.

Emilio Lapenna, Francesco Cardellicchio, Teresa Laurita, Isabella Zaccardo, Serena Trippetta, Davide Amodio, Aldo Giunta, Antonella Buono, Alessandro Mauceri, Lucia Mona

CNR-IMAA, Potenza, Italy

Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

At the Istituto di Metodologie per l'Analisi Ambientale of the Italian National Research Council (CNR-IMAA) we have completed the construction of the new ICOS-compliant Class 1 POT station tower and the implementation of the laboratory systems. In order to perform preliminary test of the entire system with the a first characterization of the site from the point of view of greenhouse gases, we plan to start the measurmentes within the next 4 months.

Our station will provide important measures within the ICOS network since in the Mediterranean basin there is only one Class 1 station. We recall that our site is located in Tito (Southern Italy, 40.60° N, 15.72° E, 760 m asl), close to Potenza City (~ 7km), in a plain surrounded by low mountains (below 1100 m asl), less than 150 km from the West, South and East coasts. It is characterized by a typical mountain weather strongly influenced by Mediterranean atmospheric circulation, resulting in generally dry, hot summers and cold winters.

The station is located close to the CNR-IMAA main premises which hosts an operative ACTRIS site providing atmospheric measurements since 2000, giving us the opportunity to study and characterize atmospheric circulation with an overarching approach, by performing synergistic investigation of GHGs and atmospheric aerosol, also considering the hints that can be derived by continuous measurements of isotopic mixture of carbon dioxide $^{14}CO_2$ in order to disentangle the anthropogenic pollution sources and their evolution with time.

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A single instrument for simultaneous monitoring of greenhouse gases and air pollutants

MORTEN HUNDT, JONAS BRUCKHUISEN, MARCO BRUNNER, OLEG ASEEV

MIRO Analytical, Wallisellen, Switzerland

Theme

18. Manufacturers' Session

Abstract Text

Monitoring of GHG combined with measurements of air pollutants and trace gases is key to understand interaction between different compounds, atmosphere, plants, and soil and therefore to improving our understanding of the climate system in general. Complex systems, in environments where both biogenic and anthropogenic sources and sinks play a role, require measurement of many different inert and reactive trace gases and GHGs simultaneously to obtain the complete budget.

Until recently, however, the monitoring was usually limited to only few gases per device making the technique complex and expensive but providing only limited pictures. MIRO Analytical developed a novel multicompound gas analyzer (MGA) that can monitor simultaneously with high precision up to 10 greenhouse gases (CO_2, N_2O, H_2O and CH_4), air pollutants (CO, NO, NO_2, O_3, SO_2 and NH_3) and other atmospheric trace gases (OCS, HONO, CH_2O) at ppb level or even lower.

We provide robust, reliable and compact laser absorption spectrometer combining several mid-IR lasers (QCLs). With a time-resolution of 10Hz, an outstanding precision, selectivity and accuracy and an automatic water-vapor correction, it is therefore well suited for eddy covariance (eddy flux) investigations.

In our contribution, we will introduce the measurement technique and will demonstrate application examples of this all-in-one atmospheric gas monitor. The system will be compared to alternative devices in parallel measurements and results of long-term observations at atmospheric measurement station and shorter campaigns will be presented. We will demonstrate that our MGA is fulfilling all requirements to be an ICOS compliant instrument.

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Assessing LAKE 2.0 model performance in simulating thermal and greenhouse gases dynamics in a small boreal lake in southern Finland

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

Lakes are significant sources of carbon dioxide and methane to the atmosphere. In addition, the lake mixing regimes and carbon budget are changing rapidly in response to the influence of climate change. Being able to accurately simulate thermal and gas related dynamics thus turns out to be a relevant task because it enables the prediction of future shifts in temperature patterns and gas exchange rates between lakes and the atmosphere. Despite this, however, most field and modeling studies have focused on the open-water season or summer with limited consideration of seasonal and interannual variability.

Here, we use the one-dimensional model LAKE 2.0 to simulate profiles of temperature and dissolved gas concentration in Lake Kuivajärvi (southern Finland). Model's performances are assessed by using high frequency and multiple years field measurements with special attention to shoulder seasons (spring and fall).

Seasonal dynamics of water temperature and gases are effectively reproduced by the model (Root Mean Square Error for water temperature 1.8-2.4 °C over the entire column). Focusing on shoulder seasons, there are some shifts in gas accumulation amount and timing which are highly dependent on the model's ability to accurately simulate temperature dynamics. These biases are particularly evident in early warm winters when the presence of thin and intermittent ice cover prevents gas accumulation. As these conditions will likely occur more often in a warmer climate, models should be able to accurately simulate these dynamics as well.

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Evaluation of Source and Sink Contributions to Urban Flux Tower Measurements Using Flux Footprint Modelling

Betty Molinier[1], Natascha Kljun[1], Patrick Aigner[2], Dominik Brunner[3], Jia Chen[2], Andreas Christen[4], Lionel Constantin[3], Hugo Denier van der Gon[5], Rainer Hilland[4], Daniel Kühbacher[2], Stavros Stagakis[6], Ingrid Super[5]

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Greenhouse gas (GHG) emissions from cities are important due to the broad mixture of their sources, their magnitude, and the large percentage of humans working or residing in these environments. Therefore, targeted reduction of urban GHG emissions is highly relevant for climate change mitigation plans. As part of the ICOS Cities/PAUL project, GHG flux measurements using the eddy-covariance technique have been established in three pilot cities (Zurich, Paris, Munich) to understand how city size/structure and sink/source mixture affect GHG emissions. However, flux measurements alone cannot answer all questions concerning emission sources and paths for reduction. The relative importance of different sectors contributing to measured fluxes needs to be determined, e.g., by using a flux footprint model to describe the spatial extent and temporal variation of the sources contributing to the measured fluxes.

We present footprints and land cover type contributions for the flux towers of the three ICOS pilot cities using the Flux Footprint Prediction (FFP) model (Kljun et al. 2015) to bridge the gap between emissions and source attribution. We show how the relative contributions of sources and sinks vary temporally by city. We also combine our footprint calculations with CO_2 flux estimates and highly spatially- and temporally-resolved emission inventories in all three pilot cities. The presented first results are a valuable step forward in evaluating emission inventories and attributing emissions to various sectors. This enables us to identify disparities in our understanding of urban emissions and which sectors to target in local climate action plans.

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Map-IO: atmospheric and oceanic observation program in the Southern Indian Ocean

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Due to its remoteness, the Southern Ocean is one of the least studied areas in the world. The MAP-IO program (Marion Dusfresne Atmospheric Program - Indian Ocean) aims to compensate for the lack of observation in this region of the globe by equipping the Marion Dufresne ship with a set of in-situ and remote sensing instruments for the study of the atmosphere and ocean. MAP-IO does not organize specific campaigns, but operates several analyzers on all the ship's routes, most of which take place in the Southern Indian Ocean. As part of this full instrumental package, a complete greenhouse gases (GhG) equipment has been installed in November 2020, including a continuous high precision analyzer (providing CO2, CH4, CO measurements), a calibration and quality control setup and intake line and a GPS positioning system. El Yazidi et al. (2018) method to detect spikes is applied to filter the major contaminations from the ship's chimney, based on the CO variability.

In this presentation, we will review the measurements obtained, their integration into the surface measurement network, and their comparison with different atmospheric model simulations (CAMS reanalysis, LMDz, TM3). Depending on the ship's positioning and the season, the gradients observed are more or less affected by air/sea CO2 fluxes, and by exports from southern African continent. A study of the various campaigns carried out since 2020 enables us to assess the contribution of this new observation program to a better understanding of CO2 gradients in this part of the world.

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Long-term trend of anthropogenic emissions measured with eddy covariance in Firenze

Tommaso Giordano[1,2], Simone Putzolu[1], Lorenzo Brilli[1], Valentina Marchi[1], Alessandro Zaldei[1], Carolina Vagnoli[1], Giovanni Gualtieri[1], Beniamino Gioli[1]

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

The IT-OXm ICOS Associated site is located in the central area of Firenze, Italy, measuring fluxes on a footprint area made by >90% of anthropogenic land uses. The site has been operational since 2005 despite some data gaps, offering the opportunity to assess long-term trends of surface emissions. Fluxes were aggregated and gap-filled at a weekly scale and then subject to trend analysis using the Mann-Kendall test before and after the COVID outbreak. Yearly fluxes spanned from 17.5 (2015) to 35.2 (2023) kgCO_2 m^{-2} y^{-1}. A significant emission reduction of 1.42 kgCO2 m^{-2} y^{-1} was observed from 2006 to 2015, followed by a period (2016-2019) with an uncertain trend due to a data gap, while a significant increase of 4.30 kgCO_2 m-2 y^{-1} was observed from 2020 to 2023. While the 2020 emissions are among the lowest due to the COVID restrictions effect, the 2023 emissions are the highest measured. Analyzing touristic flow data, a positive significant correlation between amounts of non-resident citizens and CO2 emissions in the last 3 years was observed. However, the sole official tourism inventorial data do not completely explain the observed emission increase, suggesting that emission sources are not entirely mapped by inventorial data. These data highlight that decarbonization policies to reach carbon neutrality (Firenze is among the 100 EU climate-neutral cities by 2030) under scenarios of an increasing number of citizens, both residential and touristic, remain challenging and call for structural investments in the decarbonization of buildings, services, and mobility.

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Effects of management and temperature anomalies on grassland CO2 fluxes using a long-term eddy covariance dataset

Bruna Winck[1,2], Juliette Bloor[2], David Colosse[2], Olivier Darsonville[2], Luc Michaud[2], Katja Klumpp[2]

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

Air temperature (T_{air}) anomalies and their extremes such heatwave cold spells have the potential to modify ecosystem functioning and delivered services. To date, few studies have investigated the combined effect of T_{air} anomalies and agricultural management on CO_2 flux components using long-term data. Here, we analyzed long-term carbon fluxes and T_{air} data (2003-2021) for interactions between T_{air} anomalies and flux anomalies, for two upland grassland management treatments (low and high cattle grazing). The grassland site experienced on average a month of anomalous temperature (colder/warmer) and ~10 days of extreme events per year. CO_2 fluxes were most affected by T_{air} anomalies at the start of the growing season, period during which the strongest increases of gross primary productivity (GPP) and ecosystem respiration (Reco) were observed. However, these effects were season and treatment-dependents. GPP and Reco tend to increase in warmer days except in summer and autumn, where CO_2 fluxes have been down-regulated under extreme warm conditions (> 6 days of anomalous T_{air}). CO_2 fluxes were reduced likely due to the exceedance of T_{air} stress threshold, which here was identified at 20°C. Analyses suggest a greater sensitivity to T_{air} anomalies for high versus low grazing management, highlighting the importance of management x climate interactions. Our findings evidenced the use of long-term data at fine-scale improves our understanding on the importance of timing and the nature of T_{air} anomalies on CO_2 fluxes.

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Tools for Easy Analysis of ICOS data

Ida Storm[1,2], Ute Karstens[1,2], Claudio D'onofrio[1,2], Alex Vermeulen[2,1], Klara Broman[1,2], Jonathan Schenk[1,2], Oleg Mirzov[1,2], Zois Zogopoulos[1,2], André Bjärby[1,2]

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Theme

16. Continuous Learning in a changing world - Teaching and learning novel tools & methods used for measurement techniques', data & policy

Abstract Text

If you are looking for data on greenhouse gases, the ICOS data portal is an excellent starting point. A faceted search helps you to navigate an extensive data repository, with datasets from the ecosystem, ocean, and atmosphere. Many datasets can be previewed directly on the portal through interactive graphs. For further analysis, it is possible to download the data directly from the portal. However, there is another way. Join this session to let us show you! No need to download the data to your computer – instead, bring the computation to the data. Together, we will explore how to navigate from the ICOS data portal to our ICOS Jupyter service, a free virtual research environment (VRE) provided by ICOS. Here, the ICOS Python libraris will be showcased, and you can either just watch or choose to follow along on your own computer. For the latter all you need is an internet connection and a web browser. The VRE enables instant analysis and the creation of various types of graphs, without having to install fancy software on your local computer. The process is designed to be smooth and user-friendly, suitable for both beginners and experts.

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Influence of deep stratosphere-to-troposphere transport to atmospheric carbon dioxide and methane at the Mt. Cimone WMO/GAW Global Station (2165 m a.s.l., Italy) over 2015 - 2022

Pamela Trisolino[1], Davide Putero[2], Paolo Cristofanelli[1], Jgor Arduini[3], Michela Maione[3], Francesca Marcucci[4], Stefano Amendola[4]

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

This work was dedicated to provide a first systematic assessment of the role played by deep stratosphere-to-troposphere transport events (denoted as “stratospheric intrusions (SIs)”) in influencing the CO_2 and CH_4 variability at a high mountain site in Italy (Monte Cimone, CMN, 2165 m a.s.l.). To select SI events, we used a methodology based on the analysis of the temporal variability of in-situ observed stratospheric tracers (O_3, CO and RH), modeled PV along 5-day back-trajectories starting at the measurement site, and satellite measurements of total column ozone (TCO). For 2015-2022, 9.8% of the hourly data were selected as influenced by SI events. The systematic analysis of the SI effect on CO_2 revealed differences between vegetative and non-vegetative seasons: during May-September, air masses from the stratosphere were richer in CO2 (+1.2 ± 1.3 ppm, average ± 1σ). On the contrary, during the cold months, air masses from higher altitudes were characterized by a lower amount of CO_2 (-1.2 ± 0.8 ppm). Furthermore, SI events were usually characterized by an overall decrease in the CH_4 compared to the remaining data throughout the solar year (with averaged values ranging from -7.6 to -16.1 ppb as a function of the seasonal period). However, based on the analysis of seasonal anomalies of residuals, it looks that SI events did not play a major role in determining the interannual variability of CO_2 and CH4 at CMN.

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Forest and grassland potential response to changing climate conditions: quantifying carbon and water flux dynamics in Central Germany

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

In climate-change context, characterized by increasing temperatures and frequent drought events, understanding the response of ecosystems' carbon and water fluxes becomes essential. This study aims to evaluate the carbon (C) and water flux dynamics in two distinct ecosystems, mixed deciduous forest (Hohes Holz, DE-HoH) and extensively managed grassland on drained peatland (Am Großen Bruch, DE-GsB), in Central Germany. Here we aim to understand which environmental drivers influence fluxes, and identify potential C sinks, particularly under drought. Eddy covariance towers at both sites have monitored fluxes since 2015, revealing divergent carbon and water flux responses between ecosystems. The forest site was a consistent C sink throughout this period (-360 ± 71 gC a^{-1}). However, the grassland transitioned from C source to sink in some years (+176 ± 191 gC a^{-1}, excluding lateral flows, e.g, fertilization, harvests) with elevated net ecosystem exchange (NEE) in 2019 (+442 gC a^{-1}). In terms of Evapotranspiration (ET), both sites presented stable sums, around 557 ± 23 mm a^{-1} in forest and 391 ± 19 mm a^{-1} in grassland. Air and soil temperature, VPD, and net radiation exerted significant influence on ET and carbon uptake. NEE was strongly related to meteorological drivers in forest compared to grassland. Differential responses of NEE and ET indicate distinct ecosystem water use efficiency. Further research incorporating structural attributes and additional data (e.g., leaf area, biomass), particularly during drought periods, is justified to enhance our understanding of ecosystem responses to climate change-induced stress events and the role of ecosystem structure therein.

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Transparent Horizons: IMEO's Methane Data Empowering Global Action

Andreea Calcan[1], Daniel Zavala-Araiza[2], Steven P. Hamburg[2], Xuefei Li[1], Stefan Schwietzke[2], James L. France[2], Cynthia Randles[1], Marci R. Baranski[1], Meghan Demeter[1], Robert Field[1], Manfredi Caltagirone[1]

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Theme

13. In situ data for climate and other environmental services and policy support

Abstract Text

Ambition on methane emissions reduction is growing, and open, reliable, measurement-based and actionable data is essential to track changes in emissions over time. The ability of countries and companies to meet their goals relies on their ability to target action at the speed and scale required, as well as being able to demonstrate progress towards these goals.

As a core implementing partner of the Global Methane Pledge, the UN Environment Programme's International Methane Emissions Observatory (IMEO) has been tasked with creating a sound scientific basis for methane emissions estimates and is providing reliable, public, policy-relevant data to facilitate actions to reduce methane emissions. IMEO is collecting and integrating diverse methane emissions data streams, including satellite remote sensing data, science studies, national inventories, and measurement-based industry reporting to establish a global, centralized public record of empirically verified methane emissions.

Here, we will show the progress of IMEO towards developing its global, public dataset of policy-relevant methane data, highlighting successful mitigation case studies from the pilot phase of IMEO's Methane Alert and Response System (MARS), and from IMEO's Methane Science Studies around the world across multiple anthropogenic methane emission sectors. We demonstrate how empirical data can drive real, tangible mitigation action in countries. We will also open the discussion on how IMEO could potentially collaborate with other research infrastructures such as ICOS.

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Quantifying biogenic CO_2 fluxes in urban areas using field observations

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

The natural processes of photosynthetic CO_2 uptake and plant-soil respiration, often described by the term biogenic CO_2 fluxes, are seldomly considered in the annual urban greenhouse gas inventories, assuming minor contributions compared to the anthropogenic emissions. Nevertheless, the introduction of observation-based emission monitoring approaches requires high temporal resolution flux estimations (e.g. hourly) where urban biogenic CO_2 fluxes can significantly affect the anthropogenic emissions (e.g. during summer daytime hours). Several ecosystem models have been recently used to simulate the urban biogenic CO_2 fluxes in high spatiotemporal resolution, but their performance is mainly evaluated in natural ecosystems using eddy covariance flux observations. Their effectiveness in the urban environment remains largely unknown.

This study presents a new approach for the estimation of hourly urban biogenic CO_2 fluxes based mainly on field observations, designed for the ICOS-Cities project, and applied on several locations of Zurich, Munich and Paris. The approach depends on continuous observations of tree sap flow, soil temperature, soil water content, phenology imagery, and local meteorology, as well as regular field campaign measurements of tree leaf area index and soil-leaf gas exchanges. These observations are used to derive key ecophysiological parameters and calibrate empirical environmental response functions to estimate hourly biogenic CO_2 fluxes representative of the measurement locations. The fluxes are compared between locations and cities to identify possible effects of urban surroundings and management practices on the urban biospheric processes. The potentials and limitations of the approach are discussed in the perspective of future applications in urban greenhouse gas observatories.

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Evidence of ongoing SF_6 emissions in Germany

Katharina Meixner[1], Andreas Engel[1], Tanja Schuck[1], Thomas Wagenhäuser[1], Cedric Couret[2], Kieran Stanley[3], Alistair Manning[4], Jordan Armin[5], Xochilt Gutièrrez[5], Tobias Kneuer[6,7], Dagmar Kubistin[6,7], Matthias Lindauer[6,7], Jennifer Müller-Wiliams[6,7]

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Sulfur hexafluoride (SF_6) is a potent greenhouse gas with a Global Warming Potential (GWP) of 24,700 over 100 years and is used mainly in electrical switchgear. Several global and regional measurement networks, including the AGAGE, NOAA, GAW and ICOS programmes, have been measuring surface-based SF_6 for several years. These measurements and inverse modelling have shown that there are still significant SF_6 emissions in Western Europe, with the largest source estimated to be in southern Germany. Time series of SF_6 in Germany are available from the following stations: Taunus Observatory (AGAGE), Zugspitze / Schneefernerhaus (UBA Germany, GAW, ICOS), Karlsruhe (DWD, ICOS), Hohenpeissenberg (DWD, GAW, ICOS), Lindenberg (DWD, ICOS), Ochsenkopf (MPI-BGC, ICOS), Steinkimmen (ICOS) and Gartow (ICOS).

This distribution of observation sites provides good spatial and temporal resolution of the atmospheric SF_6 dry mole fraction in Germany. The observation of persistently elevated mixing ratios is indicative of continuing local emissions in Germany. Depending on the wind direction, the highest levels of SF_6 were measured at Zugspitze, Karlsruhe and the Taunus Observatory. The Karlsruhe station stands out with maximum mixing ratios of over 70 ppt under easterly wind conditions.

In addition to the analysis of such pollution events, the observations are also used together with other ICOS and AGAGE sites in Europe in the top-down inverse model InTEM (Inversion Technique for Emission Modelling) coupled to the atmospheric transport model NAME (Numerical Atmospheric Dispersion Modelling Environment). The initial model results identify a source in Southwest Germany accounting for approximately 35% of German SF6 emissions.

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Anthropogenic emissions measured with eddy covariance in two "climate-neutral by 2030" nearby italian cities

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Eddy covariance flux measurements in urban environments are presented in two adjacent cities (Firenze and Prato, Italy) among the EU 100 climate-neutral cities by 2030, for the past three years. These cities have similar land use distribution and urban neighborhood morphology, with almost fully anthropized footprint surfaces but different pressures from residential, commercial and tourism sectors. Hourly diurnal cycles were well correlated between the two sites during the cold season ($r = 0.94$) while were not correlated during the warm season. Yearly seasonal patterns at weekly scale were also very well correlated ($r > 0.9$), and showing peak to mean ratios of 0.75 and 0.93 in Firenze and Prato respectively. These patterns reflect a similar temporal distribution of natural gas heating usage. By contrast, total emissions were always higher in Firenze: while in 2021 emissions were 34% higher, they were 52% higher in 2023. The emission gap between the two cities increased in the last 3 years, mostly as a consequence of the increasing touristic pressure in Firenze, while they maintained basically stable at Prato, which was not subject to such pressure. This observed pattern poses a challenge in choosing pathways toward carbon neutrality, indicating that along with infrastructural interventions, also citizen pressure, both residential and touristic, should be carefully considered in designing emission reduction policies in many European cities.

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GBOV (Copernicus Ground-Based Observation for Validation): an overview of the service.

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ACRI-ST, Sophia Antipolis, France

Theme

13. In situ data for climate and other environmental services and policy support

Abstract Text

GBOV (Copernicus Ground-Based Observation for Validation), is an element of CLMS (Copernicus Land Monitoring Service ; https://land.copernicus.eu). Its main purpose is to collect worldwide ground data to support Copernicus Land Service validation strategy. The Land service provides a wide range of bio-geophysical parameters including soil moisture, snow, temperature, reflectance, vegetation and water bodies. GBOV focuses on seven core land service products (TOC-R, Albedo, LAI, FAPAR, FCOVER, SSM and LST), five of whom are listed among GCOS Essential Climate Variables (ECV).

ICOS is one of the main sources of ground data to GBOV together with other networks like BSRN, NEON, TERN, SurfRad etc. Ground measurements (the so-called “Reference Measurements”) cannot be directly used for satellite data validation mostly because of ground heterogeneity: the footprint of a ground sensor is generally not comparable to a satellite pixel. Up-scaling procedures have to be applied to these ground measurements in order to generate a measurement comparable to a satellite pixel, the so-called “Land Products”. GBOV service is freely accessible on https://land.copernicus.eu/global/gbov and provides Land Products over 112 sites.

GBOV additionally deploys its own instruments as part of collaborations with the existing networks. Seven ground stations have been upgraded with additional instrumentation since 2018. In 2024, a vegetation station has been installed over Fontainebleau research station (France). Fuji Hokuroku (Japan) and Litchfield (TERN network Australia) will receive a GBOV LST station in 2024.

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Measurements and calibration for high precision continuous monitoring of stable isotope ratios in atmospheric methane

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Theme

1. Isotopes and other tracers for studies of methane sources and sinks

Abstract Text

Uptake of continuous monitoring of $\delta^{13}C$ and $\delta^{2}H$ isotope ratios in atmospheric methane is limited by the difficulty in making high-quality measurements with sufficient precision. Optical isotope ratio spectroscopy (OIRS) has the potential to provide measurements needed for emissions source sector disaggregation but is limited by the availability of suitable reference materials, and the traceability of in-field calibration.

We will present the measurement system and calibration protocols developed for $\delta^{13}C(CH_4)$ and $\delta^{2}H(CH_4)$ measurements by Boreas, an automated cryogenic preconcentrator and laser spectrometer, developed at NPL. The calibration strategy uses synthetic reference materials prepared gravimetrically from a single high-purity CH_4 parent, alongside a single compressed air standard. Both the parent methane and compressed air methane are isotopically characterised by IRMS. Other CH_4 mixtures are used to validate the calibration, and we will show that the combined uncertainty of a measured isotope ratio is dominated by the contribution from the isotope ratio of the high-purity CH_4 parent. We also quantify the uncertainty budget over the amount fraction and isotopic composition ranges of the instrument.

The system was deployed in 2021 to tall tower observatory located south of London at Heathfield, a GAW regional station for continuous regional-scale monitoring of CH_4 isotope ratio. We will show the calibrated $\delta^{13}C(CH_4)$ and $\delta^{2}H(CH_4)$ timeseries, which displays significant variation from baseline during pollution episodes with changes typically resulting from a mixture of sources.

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A Vegetation Photosynthesis and Respiration Model (VPRM) for the post-MODIS era

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

The data-driven VPRM model is a simple light-use-efficiency model, driven by satellite-derived indices of Enhanced Vegetation Index (EVI) and Land Surface Water Index (LSWI) to extract information at high spatial resolution. High temporal resolution is provided through meteorological driving data, namely 2-m temperature and shortwave radiation at the surface. Four parameters per vegetation type are fit using eddy flux tower measurements. VPRM is widely used to model carbon exchange between the land biosphere and the atmosphere. A common application is as a background (prior) model for estimating carbon fluxes through inversion techniques at regional scales, given the high temporal and spatial resolution of the fluxes compared to complex process models.

Historically, VPRM relied on data from the 500-m-resolution MODIS satellite and a static 1-km land cover classification map. As MODIS approaches discontinuation, we present an updated VPRM software framework - pyVPRM - capable of handling satellite data from MODIS, VIIRS, and Sentinel-2, as well as high-resolution land cover products, e.g. ESA WorldCover or the Copernicus Global Land Service. The extremely high spatial resolution of the Sentinel-2 reflectances and updated land cover maps now allows vegetated area within cities and crop fields to be resolved. In addition, the framework naturally provides an interface to generate VPRM inputs for use in online mesoscale models, such as the greenhouse gas module of the Weather Research and Forecasting Model (WRF). In our presentation we provide an overview of the new model and show exemplary applications across Europe from city to continental scale.

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A new age of autonomous marine carbon system observations: An evaluation of *in situ* Lab-On-Chip carbonate sensors in recent applications

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Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

In a world where the climatic response to human carbon emissions has reached a critical point in time, understanding the ocean's role in carbon cycling has become a major focus for scientific observation and intervention. The development of marine autonomous platforms and *in situ* sensing provides observations of higher spatiotemporal resolution which can be used to further measure, characterize, and model ocean carbon. Additionally, the versatility of autonomous technology affords us the ability to adapt its application to measure different environments and ocean processes. Here, we present results from a range of observing applications using novel Lab-On-Chip (LOC) pH and Total Alkalinity (TA) sensors integrated onboard autonomous platforms and discuss methods for data processing and quality control. Examples include pH and TA data collected by the Autosub Long Range (ALR) Autonomous Underwater Vehicle (AUV) (Boaty McBoatface) on the Celtic Shelf margin where pH and TA LOC sensors were used to constrain the carbonate system of the water column across different physical and biogeochemical gradients. Results will also be presented from the ALR's longest continuous deployment on record- spanning over 2000 km over 5 weeks with pH sensors onboard. Finally, we will demonstrate the potential of these technologies for characterising coral reef biogeochemistry and carbonate system dynamics following recent moored deployments in the central Red Sea. Based on the collected data and our experience in the field, the performance of this new technology and its potential as a tool for ocean CO_2 observations will be broadly evaluated.

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Trainou super site for measuring greenhouse gases in Europe, combining ICOS, TCCON and AIRCORE

Michel Ramonet[1], Morgan Lopez[1], Louis-Jeremy Rigouleau[1], Thorsten Warneke[2], Cyril Crevoisier[3], Céline Lett[4], Thomas Laemmel[5], Julien Moye[1], Dylan Lopez[1], Massaer Kouyaté[1], Francois-Marie Bréon[1]

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

The Trainou Tower station (TRN) is located in a rural area in France (47°57'53"N, 2°06'45"E), hundred kilometers south of Paris. Greenhouse gas (GHG) monitoring at this tower was initiated in spring 2007 as part of the European CHIOTTO project, and integrated into the European ICOS network in 2017. Concentrations of CO_2, CH_4, N_2O and CO are measured continuously at 4 sampling heights (5, 50, 100, 180m). The surface program was supplemented by measurements of total GHG columns in 2009, as part of the TCCON network (Orléans site), and by regular measurements of AIRCORE vertical profiles, up to 25 km, since 2018. This co-location of infrastructures dedicated to GHG measurements, unique in Europe, enables us to analyze the coherence and complementarity of these three observation methods. We will present the seasonal cycles and long-term trends deduced from Trainou observations, at different altitudes from the surface to the stratosphere. Total columns of CO_2, CH_4, N_2O and CO estimated by combining in-situ vertical profiles from the ICOS tower and Aircores, will be compared with columns measured by remote sensing from the ground (TCCON) and space. Trainou's datasets will be compared with simulations from various atmospheric transport models (CAMS, LMDz, TM3) to assess the benefits of co-locating observation programs, and to evaluate the ability of these models to reproduce observations in a rural area regularly disturbed by emissions from the Paris region.

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From tree to forest: how extreme events alter growth and water status - a six year study

Fran Lauriks

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

Heat waves and dry spells are increasing in intensity and frequency as a result of climate change. Despite their alarming relevance, impact of these events on tree and ecosystem responses remain poorly understood. Over the past six years point dendrometers have monitored tree growth and water status of five pine (*Pinus sylvestris* L.) trees at the ICOS forest site in Brasschaat. In parallel gross primary production, net ecosystem exchange, and latent heat fluxes were estimated using the eddy covariance method. From 2018 to today the forest was exposed to a sequence of extreme events including the 2018, 2020 and 2022 heat wave and the 2021 wet summer. Individual datasets provide important information on overall responses and recovering ability of single trees and the forest during and after these events. Combination of these two data sets provides a unique insight in the temporal variability of the contribution of trees to forest carbon and water fluxes over the growing season and allows evaluation of this contribution during extreme events.

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Estimating air-sea CO2 fluxes from an oceanographic tower in the Northern Adriatic Sea using ΔpCO2 and wind/wave measurements

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

The Northern Adriatic Sea is a shallow, semi-enclosed sub-basin surrounded by an industrialized area in the northeast part of the Mediterranean Sea. Episodic high wind events in this region lead to intense air-sea fluxes and favour dense-water formation, which can absorb and sequester CO2.

In this context, the oceanographic research tower "Acqua Alta" run by CNR-ISMAR, which collects atmospheric and biogeochemical ocean data in the Northern Adriatic, has been recently equipped with continuous measurements of atmospheric and surface-water partial pressure of CO2 (pCO2) to assess air-sea CO2 fluxes at this site. As for the surface forcings, given the pivotal role of wave breaking in the exchange rate of gases between the atmosphere and the ocean, measurements of surface waves and penetration depth of entrained air bubbles were also collected with an underwater ADCP echosounder. The combined dataset allows estimates of air-sea CO2 exchanges using parametrizations for the gas transfer velocity k not based solely on wind speed but also accounting for bubble-mediated effects due to wave breaking.

The set of measurements at the Acqua Alta tower over a 1-year period shows a seasonal cycle of pCO2, where surface waters are under-saturated with respect to the atmosphere in the winter months, acting as a strong sink of CO2, with enhanced air-sea fluxes up to 80 mmol m^{-2} d^{-1} during strong northeasterly (Bora) wind events. Conversely, during summer, the temperature-driven increase of surface water pCO2 shows a slight over-saturation and a much larger variability due to the particularly large summer variability of wave climate in this region and the increased biological activity.

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Assessing atmospheric fossil fuel emissions using $^{14}CO_2$ measurements and global atmospheric simulations with the CIF-LMDZ transport and inverse modeling system

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Independent monitoring and apportioning of CO_2 emissions is crucial for the verification of greenhouse gas reductions targeted by international agreements designed for climate change mitigation and adaption. Radiocarbon (^{14}C), found as a fractional isotope of CO_2, can be used as a key tracer for fossil-derived CO_2 and thus aid in the accurate apportioning of measured CO_2 that arises from fossil fuel sources compared with other emissions sources. As part of the Horizon Europe CORSO project, we are developing a dedicated atmospheric transport modeling and variational inversion configuration to assess fossil CO_2 emissions estimates at global to regional scales based on the assimilation of CO_2 and $^{14}CO_2$ measurements that are collected using central-European atmospheric ICOS stations combined with global background stations. The modeling and inversion framework is based on the Community Inversion Framework (CIF) coupled to the LMDZ global transport model with fluxes and isotopic signatures from terrestrial, oceanic, fossil fuel, nuclear, and cosmogenic sources. We conduct a multi-decadal analysis of the CO_2 and $^{14}CO_2$ emissions derived from this framework.

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Disentangling the role of plant phenology in regulating methane emissions from a northern peatland: results from a 10-year data archive

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

Northern peatlands are a globally important source of methane (CH_4), a potent greenhouse gas. However, current estimates of these emissions are poorly constrained due to their strong spatiotemporal variability and a lack of long-term datasets. While studies at the plot-level (0.1-1 m^2) have shown that the presence of aerenchymous plant species can explain CH_4 emissions spatially; routine measurements of temperature and water-table depth have commonly been employed to explain temporal variability in emissions. However, as CH_4 is produced from plant substrate, the seasonal development of vegetation or 'phenology' is likely to be another important driver of emissions. Understanding how plant development affects CH_4 production over the growing season is key for improving process-based models of CH_4 emissions, but has so far been hampered by a lack of continuous phenology data. This study employs a unique 10-year archive of eddy-covariance measurements and phenocam imagery to disentangle the role of peatland phenology in regulating temporal variability of CH_4 emissions at the ICOS Degerö peatland, northern Sweden. We use path analysis to better understand the network of biotic and abiotic drivers of peatland CH_4 emissions, and how these drivers vary over the course of the growing season. These findings are key to reducing uncertainty in estimates of current and future CH_4 emissions from these ecosystems.

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Estimation of the fossil-fuel fraction of CO_2 measured in Paris based on radiocarbon, and co-emitted species (NOx, CO, BC)

Ingrid Chanca[1,2,3], Laura Bouillon[1], Nicolas Bonnaire[1], Markus Eritt[3,4], Lorna Foliot[1], Cécile Gaudry[1], Valérie Gros[1], Xochilt Gutierrez[3,4], Samuel Hammer[5,6], Carmen Kalalian[7], Guillaume Nief[1], Jean-Eudes Petit[1], Michel Ramonet[1]

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Urban and industrial areas are major contributors to global fossil fuel CO_2 (ffCO_2) emissions, but accurately quantifying these emissions is challenging. The PAUL (ICOS-Cities) project in Paris has been using ambient air sampling since March 2023 to estimate radiocarbon (^{14}C)-based ffCO_2 levels. Samples are collected from a background station (Meudon, MEU) located in a forested area southwest of Paris, and a signal station (Romainville, ROV), positioned approximately 20 km northeast of MEU, based on the dominant wind direction; Air samples are collected into flasks by automated samplers (MEU: RINGO; ROV: ICOS flask sampler). The sampling strategy follows a Lagrangian approach and samplings are conducted when an air mass crosses the urban area of Paris, i.e. passing by both sites within a radius of 5 km. High-precision measurements of ^{14}C-CO_2 and co-emitted species (NOx, CO, BC) in situ and/or flasks were used to estimate the anthropogenic fraction of CO_2 emissions in Paris. NOx, CO, and BC measurements are used as tracers for specific sources (e.g. traffic, heating). Based on $\Delta^{14}C$-CO_2 and CO_2 concentrations for pairs collected between March and September 2023, ffCO_2 estimates vary between 0.5 and 5.4 ppm (median = 1.6 ppm) in both spring and late summer. The variation in CO_2 concentration ranged from 1 to 6.8 ppm. In June/July, ffCO_2 estimates vary from negative values to up to ca. 4 ppm. These findings provide valuable insights for comparing emission inventories and improving our understanding of urban carbon dynamics.

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Fusion of PRISMA and Sentinel-2 imagery with biophysical models for plant functional retrievals in ICOS sites across Europe

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

Plant functional traits retrievals with earth observation systems provide crucial insights into photosynthesis rate, plant health or gross primary production (GPP). Variations in the retrieved parameters may indicate biotic or abiotic disturbances such as pest outbreak, seasonality variations, or drought. Harmonizing information of the hyperspectral PRISMA satellite with the short revisit time of the Sentinel-2 (SE-2) mission allows leveraging their capabilities for plant traits monitoring. This study assesses a hybrid machine learning (ML) approach coupling radiative transfer models (RTMs) and optical satellite imagery across different Integrated Carbon Observing System (ICOS) sites.

The specific objectives are i) to develop a hybrid ML framework to estimate key plant traits (e.g., leaf area index and nitrogen concentrations) by coupling PRISMA and SE-2 spectral resolution at the site of San Rossore 2 ICOS Ecosystem Station, Italy, ii) to utilize the plant traits derived with a SE-2 time series to monitor GPP fluctuations and detect the outbreak of *Fomes fomentarius* fungus in San Rossore and iii) to extend the ML methods to diverse forest ecosystems across Europe for comprehensive analysis, management and monitoring applications.

Findings demonstrate the effectiveness of the proposed PRISMA-SE-2 methods in estimating plant traits across a range of climate and forest ecosystems, including evergreen and deciduous forests, broadleaf and needleleaf forests, as well as mixed forests. Moreover, integrating the PRISMA spectral resolution within SE-2 time series enables accurate monitoring of GPP fluctuations in varied forest ecosystems. Notably, this approach facilitated the early detection of the fungal outbreak in the San Rossore forest.

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Quantifying Arctic-Boreal methane emissions using atmospheric observations and a global inverse model

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

Wetlands and lakes are a major natural source of methane to the atmosphere in the Arctic-Boreal regions. Disturbance processes associated with the permafrost thawing, driven by accelerated temperature increases, hold the potential to increase methane emissions. This, in turn, may contribute to a positive feedback that exacerbates climate change. To address this uncertainty and to better understand the role of this region in the global methane budget, we estimated global methane fluxes using the Jena CarboScope Global Inversion System, with a special focus on the Arctic-Boreal region. As data availability in this target region has increased significantly over the last decades, our estimates focus on the time period of 2010 to 2021. We used the wetland flux from the JSBACH model as prior flux and assimilated globally available atmospheric observations (105 towers in total), with a particular focus on towers within the region between 60°N and 90°N latitude, to better constrain the Arctic-Boreal estimates (22 towers). The area of interest was divided into six different regions in order to compare prior and posterior fluxes, investigate regional and interannual variability, and examine seasonal patterns. Our results indicate pronounced emission peaks during the summer months, especially from July to September. In addition, we found regional variability in emissions, with the western region of Russia having the highest emissions. Finally, we compared our estimates with previous top-down CH_4 estimates available for the same period.

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Advancements in atmospheric methane clumped isotope measurements and modelling

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Theme

1. Isotopes and other tracers for studies of methane sources and sinks

Abstract Text

The atmospheric mole fraction of methane, a potent greenhouse gas, has been rising since the 1800s, primarily due to anthropogenic emissions, while also displaying substantial multi-annual variability, with a notable stagnation period between 2000 and 2007. Various natural and anthropogenic sources, variations in the atmospheric OH concentration and other sink reactions influence the atmospheric methane concentration. Understanding the contribution of each of these factors is crucial for a comprehensive understanding of the global methane cycle.

Recent studies have shown that measurements of the clumped isotopic composition ($\Delta^{13}CH_3D$ and $\Delta^{12}CH_2D_2$) may serve as an additional tool to constrain the sources or sinks of methane [1,2]. Technical developments towards low-concentration samples facilitate such measurements of methane extracted directly from ambient air.

The first measurements of the atmospheric methane clumping anomalies show distinct signatures of about 1 ± 0.3 ‰ for $\Delta^{13}CH_3D$ and 44 ± 3 ‰ for $\Delta^{12}CH_2D_2$, strongly enriched in $\Delta^{12}CH_2D_2$ compared to all known sources [3,4]. However, these measurements reveal discrepancies with existing model predictions, highlighting significant knowledge gaps in the known clumped isotopic composition of the sources and sink fractionations. Therefore, we use atmospheric measurements, including the history of clumping anomalies reconstructed from firn air samples collected from Greenland, to develop a two-box atmosphere model that reproduces the measured values. Additionally, this optimized model is exploited to understand the influence of the different sources and sinks on atmospheric methane over time.

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Strengthening training and capacity building to improve global observations of atmospheric composition

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Theme

16. Continuous Learning in a changing world - Teaching and learning novel tools & methods used for measurement techniques', data & policy

Abstract Text

The availability of long-term, high-quality atmospheric composition observations is highly unbalanced around the globe. Thanks to a well-established tradition, funding mechanisms, and research infrastructures such as ICOS, observations are mainly available in developed northern hemisphere countries, but are often sparse in other regions.
The Global Atmosphere Watch (GAW) programme, coordinated by the World Meteorological Organization (WMO), is dedicated to providing consistent long-term observations of the chemical composition of the atmosphere on a global scale. Emphasizing rigorous quality assurance and control measures, GAW plays a pivotal role in understanding atmospheric dynamics and their implications. The new GAW Science and Implementation Plan 2024 – 2027 defines Capacity Development as one of the four major strategic objectives of the programme.
This presentation will reflect on the progress in capacity development made to date within GAW, highlight recent activities, and discuss key challenges and how they may be addressed. Furthermore, we will outline the evolving role of GAW Capacity Development. The latter involves improved post-training monitoring, expanding regional training facilities and increasing the use of online educational material, which are complementary to traditional in-person and on-site courses.
We advocate the significance of GAW observations and identify synergies with other programmes. This consolidated approach not only fortifies GAW's mission but also serves as a blueprint for WMO's forthcoming Global Greenhouse Gas Watch (G3W) initiative. G3W is an ambitious endeavor, which seeks to bolster the global greenhouse gas observing system and furnish actionable insights to stakeholders, particularly the United Nations Framework Convention on Climate Change (UNFCCC).

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Spring melting season methane emissions in the northern high latitude wetlands based on inversion modeling

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

In the high northern latitudes there are extensive wetlands, which are a source of methane. Methane emissions are characterized by a seasonal cycle corresponding to freezing and thawing of the ground. Much of the high northern latitudes are also covered by permafrost. As permafrost thaws due to climate change, these methane emissions may increase. There is still much uncertainty about methane emissions and their seasonality in these wetlands.

During the spring melting season, methane emissions increase rapidly. To gain a better understanding of emissions during this spring shoulder season, the melting season was defined using using the SMOS F/T soil state for both permafrost and non-permafrost regions for the years 2011-2021. The SMOS F/T soil state daily information on the freezing state of the soil in the northern latitudes. Methane emissions during the melting period were determined using the inversion model CarbonTracker Europe – CH4 by assimilating in-situ measured methane mole fractions including those from the ICOS stations. The emissions were found to be relatively small compared to annual emissions, with the non-permafrost region having substantially larger emissions than the permafrost regions. To understand the emissions better, the relationship between different drivers, such as the length and mean temperature of the melting season, was studied. A negative correlation between mean temperature and length, and a positive correlation between length and emissions were found.

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EYE-CLIMA: A Horizon Europe project to support national inventories for emissions of climate forcers

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Theme

13. In situ data for climate and other environmental services and policy support

Abstract Text

National greenhouse gas inventories (NGHGIs) and Biennial Transparency Reports (BTRs) on emissions and removals are crucial elements of the Paris Agreement and its Global Stocktake. However, NGHGIs are subject to significant uncertainties, owing to uncertain emission factors and/or insufficient activity data. Additional and complementary information can be provided from atmospheric inversions, which use atmospheric observations in a statistical optimization framework to estimate emissions and removals. This method of verification is referred to in the 2006 IPCC Guidelines on national reporting and the 2019 refinement. However, atmospheric inversions have been hitherto considered too complex and inaccurate at national scales to be widely used for this purpose.

EYE-CLIMA is a Horizon Europe project that aims to develop the atmospheric inversion methodology to a level of readiness where it can be used to support the verification of NGHGIs. The overarching goals are to: i) develop a best practice in atmospheric inverse modelling for estimating emissions at national scale, including full assessment of uncertainties, ii) develop the methodology on how to prepare sectorial emission estimates from atmospheric inversions and make these comparable to what is reported in NGHGIs, iii) work together with NGHGI agencies on projects piloting the EYE-CLIMA methodology of emissions verification and iv) develop international best practices for the quality control of NGHGIs. EYE-CLIMA covers CH4, N2O, 5 HFC species, SF6, and the black carbon (BC) aerosol. This presentation will focus on the set-up of the EYE-CLIMA project and provide an overview of the first results in support of NGHGI verification.

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Remote sensing measurements of greenhouse gases at Sodankylä and comparisons with satellite observations

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

At Sodankylä, Finland (67.37° N, 26.63° E) regular measurements of greenhouse gases have been performed using remote sensing techniques. The Sodankylä site participates in the Total Carbon Column Observing Network (TCCON), the Network for the Detection of Atmospheric Composition (NDACC), the COllaborative Carbon Column Observing Network (COCCON) and other ground-based networks. The ground-based measurements are frequently used to support the satellite-borne remote sensing measurements of greenhouse gases. Relevant satellite missions include the NASA OCO-2 mission; the GOSAT and the GOSAT-2 missions; ESA Sentinel 5-P; TanSat mission; MicroCarb by CNES; the Copernicus Carbon Dioxide Monitoring mission CO2M; ESA Sentinel 5; MERLIN, a joint mission by DLR and CNES and other missions. Here we present long-term measurements of greenhouse gases at Sodankylä and comparisons with satellite borne observations. High-resolution Fourier Transform infrared spectrometer has been operational in Sodankylä since early 2009. The most recent data version is based on the TCCON GGG2020 retrieval. At the Sodankylä TCCON site we have also performed balloon borne observations of greenhouse gases using AirCore technique. The AirCore observations are directly related to the World Meteorological Organization in situ trace gas measurement scales. Therefore, AirCore observations can be used for calibration of the remote sensing observations.

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Simple annual CO2 flux indicator from Sentinel-2 and ERA5 data

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

In recent projects [1,2], our team has been in charge of developing an indicator that evaluates the annual CO2 flux of agricultural parcels. The development of this indicator focussed on the scientific methodology, the algorithms, the software designs and the output production as maps [1,2]. The indicator responds to the so-called "tier 1" terminology which mean that simplicity of usage and scalabilty is prefered to high accuracy. More precisly, the indicator is independant of the type of crop or region, relatively easy to implement at large scale, and has an uncertainty that is completly characterized.

The methodology is based on the following observations [3]: at first approximation, the annual CO2 flux of a parcel seems correlated to the number of days it is covered by an active photosynthetic vegetation. The key point of the methodology is to estimate the vegetation covering from remote sensing. However, a precise in-situ validation of the method itself permormed on the agricultural ICOS sites, shows that the performances are not satisfying, even for a tier 1 approach.

With the help of the agricultural ICOS sites flux database, and the inclusion of climatic variables, an improved methodology with better accuracy for the same level of complexity is proposed.

[1] https://www.niva4cap.eu/ (H2020 project)

[2] SOCCROP project (https://www.inrae.fr/actualites/soccrop-premier-indicateur-devolution-du-stockage-carbone-sols-agricoles)

[3] Ceschia et al. Agriculture Ecosystems & Environment 139(3):363-383 (2010)

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Urban Atmospheric Monitoring Network Requirements to track CO_2 Emissions until Climate Neutrality

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Cities, accounting for over 70% of global greenhouse gas (GHG) emissions and generating more than 80% of global income, are actively enacting mitigation policies to drive climate action. Therefore, understanding in detail the spatiotemporal distribution of total urban GHG emissions is crucial for effective emission reduction strategies. This study assesses the effectiveness of urban atmospheric monitoring networks in tracking carbon dioxide (CO_2) emissions within the Paris metropolitan area in line with its climate action plan. Using a high-resolution dynamic emissions inventory and atmospheric modeling, we assess signal-to-noise ratios (SNR) of fossil fuel CO_2 concentrations to evaluate emissions detectability and the potential lifetime of our observation network as carbon emissions decrease. The network comprises different sensor types, including high-precision and medium-precision CO_2 sensors, offering a cost-effective option for densifying existing networks and providing comprehensive coverage.

Our findings reveal decreasing SNR trends and CO_2 concentration detectability (signal) until 2035-2040 for various sensor types, influenced by model errors, background concentrations, and measurement uncertainties (noise). Emission detection is influenced by both seasonal variability and spatial concentration variances. Wintertime is suitable for tracking long-term emissions trends, while significant concentration gradients exist from urban to rural areas. Adjusting the spatial coverage accordingly ensures sustained network effectiveness over time. This research highlights challenges and opportunities in urban GHG monitoring, advocating for multifaceted approaches integrating observational, experimental, and modeling methods. By illustrating emission dynamics and uncertainties, our findings support climate policies and advance emissions reduction strategies in urban environments.

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Advancing Urban Greenhouse Gas Monitoring: Development and Evaluation of a High-Density CO_2 Sensor Network in Munich

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Cities are a focus of the European Union's effort to become climate-neutral by 2050. The ICOS Cities project aims to create services for cities to assist and quantify their pursuit of gradually reducing emissions over the following decades. An essential input for this is quality-controlled atmospheric measurement data from trusted sources. In three pilot cities, Paris, Munich, and Zurich, different sensor networks were set up with varying sensor accuracy, network density, and location characteristics.

Here, we present an overview of Munich's mid-cost sensor network ACROPOLIS: **A**utonomous and **C**alibrated **R**ooftop **O**bservatory for Metro**POLI**tan **S**ensing. The network comprises 20 sensor systems on rooftops in and around the city with a targeted CO_2 measurement accuracy of 1ppm. In addition, we aim to reduce operating costs and effort by automating procedures and designing the systems as permanently connected Internet of Things (IoT) devices. Hardware and software development was carried out in-house, featuring a temperature-controlled outdoor enclosure, an automated sensor system, two calibration cylinders, and an external unit with a wind sensor and air inlet. Every sensor node uses a Vaisala GMP343 CO_2 Sensor (NDIR) complemented by auxiliary humidity, pressure, and temperature sensors.

We demonstrate our operation and calibration strategy to achieve the targeted performance and assess sensor performance primarily through Root Mean Square Error (RMSE), obtained during a multiweek outdoor side-by-side campaign with a Picarro G2301. Additionally, we will discuss sensor placement and share preliminary results from 6 months of observations in Munich.

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ICOS Carbon Portal: Services and User Experience

Ute Karstens[1,2], Claudio D'Onofrio[1,2], Margareta Hellström[1,2], Liisa Ikonen[3], Harry Lankreijer[1,2], Oleg Mirzov[1,2], Ida Storm[1,2,4], Angeliki Adamaki[1,2], André Bjärby[1,2], Klara Broman[1,2], Anders Dahlner[1,2], Remco de Kok[4], Arndt Meier[1,2], Jonathan Schenck[1,2], Jonathan Thiry[1,2], Zhendong Wu[1,2], Zois Zogopoulos[1,2], Alex Vermeulen[2,1]

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Theme

16. Continuous Learning in a changing world - Teaching and learning novel tools & methods used for measurement techniques', data & policy

Abstract Text

ICOS Carbon Portal is the data centre of the ICOS Research Infrastructure and responsible for long-term storage and dissemination all ICOS and ICOS-related data. Beyond archiving, it offers support for working with and analysing ICOS data. A diverse set of services is provided, ranging from the data discovery through a versatile search interface to models supporting the interpretation of the measurements. It also provides a virtual research environment that provides easy access to analysis tools. Recognizing the importance of user input, we take the opportunity of the ICOS Science Conference to ask the ICOS community and all users to help us to further improve and expand our services.

On this poster, we briefly introduce all our services, provide links to more detailed service documentation and invite conference participants to give us feedback on existing services, to suggest ideas for future developments or to engage in user feedback groups.

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Use of a Lagrangian transport model for atmospheric inversions using satellite observations: case study using TROPOMI to estimate CH4 emissions over Europe

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

We present a novel and computationally efficient method for atmospheric inversions of satellite observations using a Lagrangian Particle Dispersion Model (LPDM) and demonstrate its use over Europe. LPDMs have several advantages over Eulerian models. First, they can more precisely represent an observation since calculations are independent of a computational grid and second, LPDMs can be run in a backwards in time mode, which allows the computation of the sensitivity of an observation to fluxes and in this way are sometimes said to be “self adjoint”. The LPDM used in our study is FLEXPART.

In our method, FLEXPART is run in a backwards-in-time mode to determine total column source-receptor relationships (SRRs), which describe the relationship between a total column observation (such as from a satellite) and fluxes. The SRRs are used in the Bayesian inversion framework, FLEXINVERT, to optimize fluxes over a nested domain. Background mixing ratios for the total column observations are determined by coupling FLEXPART backward trajectories with the outputs of the CAMS data assimilation product, EGG4.

Using FLEXPART-FLEXINVERT, we determine CH_4 emissions over Europe using observations from the TROPOspheric Monitoring Instrument (TROPOMI) onboard Sentinel 5P. We compare results using the Official retrieval product versus the research project, WFMD, from the University of Bremen, and against results using observations from the ICOS network.

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Emission Inventory for Human Respiration: Case Study in Munich Utilizing Statistical and Mobile Network Data Methods

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

In the pursuit of comprehensive carbon dioxide (CO_2) emission inventories, understanding the contribution of human respiration is essential. This holistic view is required to bridge the gap between modeled and observed emissions, thereby facilitating more targeted climate action strategies. Consequently, alongside ongoing inventory efforts in Munich across various sectors such as public power, heating, and traffic, a novel inventory focusing on human respiration emissions has been developed. The inventory offers spatial resolution at 100 m x 100 m and time profiles with hourly intervals. Two distinct methodologies are compared: (1) a statistical approach utilizing datasets such as population demographics, land use, and time use surveys, supplemented by data sources like Google reviews, and (2) a mobile network data approach, which tracks individuals based on their mobile device signals received by nearby mobile towers. The mobile network data, pre-processed by the vendor, offer a spatial resolution depending on mobile cell density and privacy considerations. To achieve the desired finer grid resolution, downscaling is necessary. For the temporal perspective, hourly tracking of individuals in each cell unveils previously unexplored patterns. Through the analysis of results yielded by the two methodologies, the aim is to discern spatial and temporal disparities between them, identify their respective strengths and weaknesses, and propose enhancements for the more cost-effective statistical approach, leveraging insights obtained from the mobile network approach. By tailoring these methodologies to Munich's unique characteristics, a groundwork can be laid for emission inventories in other urban settings as well.

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Carbon dioxide and methane fluxes over the coastal Baltic Sea

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

The fate of carbon in the coastal sea is emerging as a vital component in the global carbon cycle. In a healthy state, the coastal sea acts as a carbon sink, but a degraded state could potentially turn the coastal sea to a source of carbon in the form of emitted carbon dioxide (CO_2) and methane (CH_4). However, the carbon budget in the coastal sea is often poorly constrained due to an inadequate amount of available data. The new ICOS Associated ecosystem site FI-Tvm commenced its operation in 2022. The station is situated in the coastal Baltic Sea by the Tvärminne Zoological Station and enables a better-constrained carbon budget in the coastal sea.

We report here the measured sea–atmosphere CO_2 fluxes between April 2022 and March 2024. The measured mean monthly CO_2 fluxes varied between −0.3 ± 0.4 µmol m^{-2} s^{-1} (± STD, net sink) and 0.4 ± 0.3 µmol m^{-2} s^{-1} (net source). The CO_2 fluxes were relatively small but most of the monthly means differed significantly ($p < 0.05$) from 0. There was a significant ($p < 0.05$) difference in the day- and night-time CO_2 fluxes from March to October, likely reflecting diurnal changes in environmental drivers. CH_4 fluxes were measured during late 2023 and early 2024. The magnitude of these fluxes was 10 ± 40 nmol m^{-2} s^{-1}. Further analysis will concentrate on better distinguishing the terrestrial influence from the sea–air fluxes, determining which environmental parameters are driving the fluxes, and flux gapfilling.

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Methane sources in Cluj-Napoca, Romania: insights from isotopic analysis

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Theme

1. Isotopes and other tracers for studies of methane sources and sinks

Abstract Text

Methane (CH_4) is a more potent greenhouse gas with a shorter lifetime than CO_2. Reduction of methane emission is necessary to mitigate climate change on short time scales. Mitigation of methane emissions requires a solid understanding of the location, strength, and source of emissions. The source can be identified by the isotopologues because different sources emit CH_4 with a different isotopic composition. These isotopologues can be measured via an isotope ratio mass spectrometer (IRMS). Utrecht University operates an IRMS system that can measure $\delta^{13}C$ and δD of CH_4. This system can be deployed at the station to measure the isotopologues at high precision with a 20-min resolution. This system is, as part of the new Horizon Europe project PARIS (Process Attribution of Regional Emissions), deployed in Cluj-Napoca. This campaign expands the coverage of high-time resolution CH_4 isotopic measurements in Europe. The goal is to investigate the typical source mix of methane in various regions and investigate whether these observations agree with emission inventories. The time-series of Cluj-Napoca indicated that the nighttime accumulation was the most persistent factor for the rise in methane mole fraction and the δD and $\delta^{13}C$. When these enhancements were evaluated, two source mixtures were observed. The main source mixture was between the gas network and a river, and the second mixture was between the gas network and a fossil source. Furthermore, it suggests that the biggest enhancements come from the city centre which contains several sources that were investigated during a mobile survey.

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Discrepancies between ICOS measurements and modelled greenhouse gas concentrations characterizing the parametrization error for greenhouse gas emission verification

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

One of the challenges of weather and climate numerical modelling is the parametrization of processes, for instance, convection and turbulence on scales smaller than the horizontal and vertical grid resolution. The parameterizations' simplifying assumptions lead, among others, to model errors. These model errors need to be characterized when performing emission estimation based on observed atmospheric concentrations (top-down emission estimation).

The integrated greenhouse gas emission verification project *Integriertes Treibhausgas-Monitoringsystem* (ITMS) for Germany aims to close the gap between bottom-up and top-down greenhouse gas (GHG) emission estimates. We use the numerical weather prediction model ICON (ICOsahedral Non-hydrostatic)-ART (Aerosols and Reactive Trace gases) to model the GHGs as tracers. We consider a limited-area domain that encloses Europe and use a 6.5-km-resolution grid. We compare ICOS measurements against corresponding model equivalents. We statistically analyze the differences in the observed and modelled methane concentration together with the differences in observed and modelled temperature and humidity, with emphasis on the vertical scale of the first few hundred meters near the ground: where the bulk of emissions, as well as the observations, take place.

This way, we identify the magnitude of errors of the parameterized processes, which, adequately considered, can subsequently improve the greenhouse gas emission verification.

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Exploring the Use of Forest Inventory Data in an Inverse Modelling System for Monitoring the European Carbon Cycle

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Forests play a crucial role in the European Union's mission to achieve net carbon neutrality by 2050. Accurate monitoring of forest CO_2 sequestration is essential for policy support, and new methods are actively developed as part of the Copernicus CO_2 monitoring and verification support (MVS) system. Inverse modelling, based on observations of atmospheric CO_2, forms a key element in such a system. CO_2 inversions can capture short-term variability in surface CO_2 fluxes, such as during droughts. However, due to rapid mixing of atmospheric CO_2, these modelling systems need additional information from local observations to be accurate across space. National forest inventories (NFIs) provide a promising observation stream of patterns of aboveground biomass, biomass increments, and forest age across space.

We introduce a framework to use information from NFIs as potential additional constraint in an inverse modelling system of the European carbon cycle. Our approach combines available forest inventory data with the forest resource simulation model EFISCEN-Space. We present an inventory-based map of forest biomass change in Europe, and show its application in an atmospheric modelling system of the carbon cycle. In addition, we compare our inventory-based map to some existing spatial data products of forest biomass change in Europe. In the near future, we focus on implementing this observation stream of European forests as additional constraint in CarbonTracker Europe, an existing inverse modelling system for the carbon cycle.

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Measurements of CO_2 fluxes over the Baltic Sea from land and ship using EC method and different gas transfer velocity parameterizations.

Iwona Niedzwiecka[1], Violetta Drozdowska[1], Malgorzata Kitowska[1], Karol Kulinski[1], Przemyslaw Makuch[1], Tomasz Neumann[2], Jacek Piskozub[1], Anna Rutgersson[3]

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

With the growing challenges of climate change, accurate estimates of air-sea CO_2 fluxes are becoming critical. To calculate CO_2 exchange rates and efficiencies and compare them with data from EC tower at Östergarnsholm Island, as well as with CO_2 flux estimates from available parameterizations to calculate the gas transfer coefficient, we are using data on pCO_2 concentrations in water and atmosphere, wind speed, and surface organic matter in the Baltic Sea (BS) obtained from a research vessel. The goal of the research is to study gas exchange at the regional scale of the BS and in detail to determine the effect of surface organic matter on the gas transfer coefficient, which are crucial to the global carbon balance. Our study focuses on the unique conditions of the BS, including periodicity of strong winds, which allow for the examination of CO_2 flux dynamics under extreme weather conditions. By comparing direct shipboard measurements with tower data and indirect methods, we aim to verify and potentially optimize existing models. Our work contributes to the expanding understanding of biogeochemical processes in the BS and their significance for the global carbon balance. The implications of our findings extend to climate change modeling and environmental policy, highlighting the critical role of diverse measurement and modeling approaches in offering a holistic view of CO_2flux dynamics. Such comprehensive insights are vital for accurately predicting and effectively managing climate change impacts at both global and regional levels.

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Impact of extreme drought events on soil carbon dynamics in mountains : experimental and observational study

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

Extreme weather events, such as droughts, are increasingly affecting mountainous regions, where soil drought is worsened by factors like reduced winter snowpack, as seen in the French Alps in 2022. These changes, coupled with intense summer rains, pose significant uncertainties for soil organic carbon dynamics in mountain soils.

To address this, we combined field observations, mesocosm experiments, and modelling approaches to investigate how drought and rain intensity affect carbon dynamics in mountain grassland.

In 2023, a short-term mesocosm experiment (4 months) was conducted, simulating a centennial drought and including two episodes of heavy rain events. Soil cores were sampled from a well-equipped mountain catchment at the Col du Lautaret, from two dominant grasslands. The cores underwent drought or control treatments in a paired design (16 mesocosms).

At the plot scale, we monitored CO_2 fluxes (net ecosystem exchange, and carbon vertical leaching); changes in microbial community composition (via DNA amplicon sequencing); and extracellular enzyme activities.

At the catchment scale, carbon fluxes were monitored through continuous measures of net ecosystem exchange (ICOS FR-Clt flux tower) as well as through the collection of dissolved and particulate carbon samples after summer storms. Finally, a ParFlow-CLM hydrological simulation was set up for the catchment to evaluate the spatial variability of soil responses to drying-rewetting cycles analogous to those experienced in the mesocosm experiment.

With this integrated and interdisciplinary approach, we provide new insights into how extreme weather events shape the dynamics of soil organic carbon in mountain regions facing rapid climate warming.

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VOC fluxes and concentrations at a boreal forest site before, during and after clear-cutting

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Theme

2. Exchange of reactive gases and aerosols between the land surface and the atmosphere in natural and managed ecosystems

Abstract Text

Vegetation is the major source of volatile organic compounds (VOCs) into the atmosphere, where these compounds have both air quality and climate effects. However, data sets on ecosystem-level biogenic VOC emissions are very limited, both spatially and temporally, and our understanding e.g. of the effects of disturbances on VOC emissions from vegetation is rudimentary. As clear-cutting is the most common harvesting method in European boreal forest, understanding its effects on BVOC emissions is an important part of understanding the climate effects of forestry.

To provide data on ecosystem-level VOC emissions, and to quantify the effect of disturbance by forestry operations, we have measured ecosystem-level VOC emissions from a boreal coniferous ecosystem before, during and after the clear-cutting by eddy-covariance method with a VOCUS PTR-ToF-MS analyzer. In addition, we have used a gradient-flux approach with GC-MS sample analysis to speciate the emitted monoterpene species. The vertical VOC source-sink distribution within the forest canopy was also determined using the vertical profile of VOC concentration and Lagrangian dispersion method.

The results indicate a large variety of VOC compounds being emitted by the forest system. These include terpenoids (isoprene, monoterpenes and sesquiterpenes). The most common monoterpenes emitted were α-pinene and Δ^3-carene. The monoterpene emissions originated in summertime mostly from the canopy, with larger contribution from below-canopy emissions during spring and autumn. The forestry operations clearly increased the emissions of certain VOC emissions, e.g. monoterpenes by an order of magnitude, persisting several months following operations, while others were unaffected, e.g. isoprene.

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Mapping of Greenhouse gases within the Greater Athens Area using mobile measurements

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Greece is a EU country in the Eastern Mediterranean aiming to comply with recommendations for decreasing GHGs emissions. Furthermore, Greece has joined the Global Methane Pledge (GMP) in order to take voluntary actions and contribute to a collective effort to reduce global methane emissions at least 30% from 2020 levels by 2030. It is well established that the primary sources of CO_2 are fossil fuel combustion and industry while the ones of CH_4 are emissions from fossil fuel use, agriculture and waste management, wetlands and other natural emissions.

In view of the above, since 2019 an ICOS-compliant cavity ring-down spectrometer (Picarro G2401) has been operating continuously at the Athens NOA urban background site. The equipment is calibrated according to the WMO-X2007 and WMO-X2004A reference scales for CO_2 and CH_4, respectively. Since fossil fuel combustion and waste management is an important source of both GHGs, specific routes were designed for mapping campaigns within Athens, to include major traffic arteries as well a sanitary landfill area, in order to characterize GHG levels within the GAA. The same routes were followed on a monthly but also weekly basis. Measurements were then compared to the urban background values, where a large burden is observed throughout the perimeter area of the landfill, which in places is two or three orders of magnitude above the background level. An increase in Δ-CO_2 values is also observed in major traffic arteries and at the entrance of the facilities and is possibility associated with the presence of waste vehicles.

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Looking beyond our Eddy-Covariance backyard – vertical profiles at ecosystem stations

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Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

The well-equipped eddy-covariance (EC) stations of the ICOS ecosystem network are ideal testbeds for tentatively measuring or estimating additional variables relevant to monitoring or modelling global change. A common limitation of a standard EC station is the confinement of most variables to the EC measurement height, which is typically limited by factors such as footprint size, the need to avoid the roughness sublayer, and tower construction costs. Few (mostly forest) stations provide some measurements below this height, and almost none offer measurements above it. Here, we present past and ongoing efforts to close these gaps.

For scalars and wind below the EC height, we developed a profiling system, that mitigates calibration issues and sensor costs by moving sensors and tubes within crop canopies and their roughness sublayer. The original system for CO_2, H_2O, wind and temperature, which moves up and down continuously at one location, is currently being replaced by a robot-arm based system to enhance flexibility in movement speed and horizontal measurement locations.

For scalars above the EC height, we demonstrated in previous research that the potential temperature of the well-mixed part of the convective planetary boundary layer can be estimated from turbulence data measured by the EC equipment. We present first steps to extend this approach to CO_2. Ultimately, we aim at testing the feasibility of this and other 'virtual tall tower' concepts for infrastructures such as ICOS. In case of a positive evaluation, spatial data density could be dramatically increased helping to verify atmospheric inverse modelling estimates.

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Novel belowground *in-situ* gas labelling approach for methane production and oxidation: case study at a boreal peatland

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Theme

1. Isotopes and other tracers for studies of methane sources and sinks

Abstract Text

Previous studies on methane (CH_4) dynamics in peatlands relied on laboratory incubations, which inevitably disrupt natural conditions and potentially skew rate estimates. To address this, we developed a novel *in-situ* gas labelling approach using passive diffusion chambers (PDC) to deliver ^{13}C-acetate, ^{13}C-CO_2 and ^{13}C-CH_4 into the peat, enabling the determination of *in-situ* potentials for acetoclastic methanogenesis (P_{AM}), hydrogenotrophic methanogenesis (P_{HM}) and CH_4 oxidation (P_{MO}).

In December 2020, we deployed 24 PDCs at depths of -30 and -50cm in Siikaneva fen, southern Finland. We conducted 11-day *in-situ* labelling compaigns in two consecutive summers. Background (non-labeled) $\delta^{13}C$-CH_4 averaged -75.9‰ (30cm) and -78.9‰ (50cm), and $\delta\,^{13}C$-CO_2 averaged -5.4‰ (30cm) and -1.9‰ (50cm). All end product values substantially increased after label injection, indicating successful implementation.

In-situ $P_{AM,}$ P_{HM} and P_{MO} showed no significant differences between the depths, with P_{AM} being 2.0 nmol $L^{-1}\,h^{-1}$, P_{HM} being 0.51 nmol $L^{-1}\,h^{-1}$ and P_{MO} being 20 nmol $L^{-1}\,h^{-1}$ at both depths. We conducted also *in-vitro* incubation in a similar way as *in-situ* measurement. *In-vitro* P_{AM} was estimated at 3.6 (30cm) and 0.4 (50cm) nmol $L^{-1}\,h^{-1}$ and *In-vitro* P_{HM} was estimated at 1.6 (30cm) and 2.50 (50cm) nmol $L^{-1}\,h^{-1}$. *In-vitro* P_{MO} showed higher rates than *in-situ* results, averaging at 253 (30cm) and 34 (50cm) nmol $L^{-1}\,h^{-1}$.

Additionally, we optimized a CH_4 process model using Trust Region Reflective algorithm incorporating both *in-situ* and *in-vitro* data. Further details and discussion will be presented during the session.

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Studying atmospheric greenhouse gas variability through synthetic satellite data generated by the DEHM model.

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

Effectively monitoring atmospheric CO_2 concentrations plays a crucial role in implementing new policies that target reductions in emissions on national basis as well as the taxation for violating these agreements. In 2026 the first of a new group of three satellites is planned to be launched as part of the Copernicus Anthropogenic Carbon Dioxide Monitoring (CO2M) mission. The new satellites will carry equipment capable of detecting anthropogenic CO_2 signals at country or megacity scales.

Several recent studies have investigated the possibilities and precision of the CO2M satellites and made comparisons to current CO_2 measuring satellites such as the Orbiting Carbon Observatory-2 (OCO-2). The CO2M mission will have higher resolution and a much wider swath, increasing from 10.3 km to 250 km.

This study focuses on modeling atmospheric CO_2 concentrations with the combined atmosphere-biosphere model of DEHM (Danish Eulerian Hemispheric Model) and SPA (Surface Plant and Atmosphere) around Copenhagen, Denmark, with the possibility to expand to other countries in Europe. The output data from DEHM will then be used to generate synthetic satellite images, that follows a setup resembling the upcoming CO2M satellites. The goal is to investigate the satellites detectability of variations in CO_2 concentrations in the atmosphere around Copenhagen.

The ongoing work of further developing the combined DEHM-SPA model setup will pe presented together with the current analysis of CO_2 variability and surface-to-column propagation within the atmosphere. Additionally, preliminary results for the synthetic satellite data will be presented and discussed.

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Continuous ΔCO-based $\Delta ffCO_2$ record of the ICOS network: signal strength and uncertainties

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Estimating fossil fuel CO_2 enhancement ($\Delta ffCO_2$) at measurement sites often relies on the well-established technique of comparing ^{14}C depletion between the site and a “clean” background station. However, this approach has been limited by the absence of sufficiently precise continuous ^{14}C observation techniques. Up-to-date, only sparse $^{14}CO_2$ grab sampling is performed. Recently Maier et al. (2023) have shown that readily available co-emitted proxies, such as carbon monoxide (CO), can serve as surrogate tracers for $ffCO_2$ providing continuous $\Delta ffCO_2$ estimates. While CO-based $\Delta ffCO_2$ assessments have primarily focused on urban areas with high fossil fuel signals, this study extends the CO-based $\Delta ffCO_2$ concept to the European scale.

We use the Integrated Carbon Observation System (ICOS) station in Mace Head (MHD), Ireland, as background reference for the European ICOS network. By combining high-precision ^{14}C-based $\Delta ffCO_2$ estimates with concurrently observed ΔCO excess, station-specific $\Delta CO/\Delta ffCO_2$ ratios are assessed. Continuous hourly CO-based $\Delta ffCO_2$ estimates can be retrieved by combining the continuous ΔCO excess records and the station-specific ^{14}C-based $\Delta CO/\Delta ffCO^2$ ratios. Our analysis also investigates spatial gradients in the $\Delta CO/\Delta ffCO_2$ ratio across Europe and compares these with expected changes derived from bottom-up emission inventories. Finally, we analyse the average ΔCO-based $\Delta ffCO_2$ signals at ICOS sites and discuss these results in the context of their uncertainties.

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The ICOS background station at Plateau Rosa and the assessment of high-resolution CH_4 simulations in complex terrain

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

In this study we analyse the methane mole fractions measured at the atmospheric station at Plateau Rosa since 2018 with a Picarro cavity ring down spectrometer G2301. The station, at 3480 meter MSL, represents an ideal location for, on one hand, measurements of background air and estimation of the global trend and, on the other hand, intercepting pollution events at regional scale. Since 2021 the site contributes as an atmospheric station to the ICOS network.

We provide an analysis of the continuous record of CH_4 since 2018 and pollution events observed at the station. We used the FLEXPART atmospheric transport model coupled to the high-resolution (1 km x 1 km) output of the numerical weather prediction model COSMO to simulate regional CH_4 contributions. We assess how well the transport model coupled to different bottom-up inventories (EDGAR, TNO, Swiss national) can capture observed variability. We focused our analysis on April 2022, when the CH_4 increment above the baseline was consistently high, and March 2024, where a CH_4 enhancement of several days was observed.

We demonstrate how the CH_4 mole fraction data measured continuously at the station at Plateau Rosa can be used to better understand CH_4 emissions in Europe and how they compare to updated inventories.

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Assessing the permanence of ocean carbon sequestration in the North Atlantic with implications for marine carbon dioxide removal efficacy and verification

Chelsey Baker, Adrian Martin, Andrew Yool, Ekaterina Popova

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Theme

8. Enhancing the ocean carbon sink: the science, verification, and governance of marine-based carbon dioxide removal (mCDR)

Abstract Text

The North Atlantic Ocean is being explored as a region for deploying marine carbon dioxide removal biomass-sinking approaches. The quantity of biomass sunk from the surface, the region and depth at which it is remineralized, and the subsequent timescale of ventilation controls the magnitude and permanence of carbon sequestration. We apply Lagrangian tracking in two ocean circulation models of medium (1/4°; eddy-permitting) to high (1/12°; eddy-resolving) resolution to determine the fate of sinking biomass in the North Atlantic. Remineralized biomass at three vertical horizons (500, 1,000, and 2,000 m) is tracked to determine how much remains out of contact with the atmosphere for 100 years. The fraction that remains below the mixed layer for 100 years is defined here as the sequestration efficiency. At each of the 500, 1,000 and 2,000 m horizons, the sequestration efficiency is 28%, 66% and 94%, respectively for the medium-resolution model and decreases to 47.5% at 1000m for the high-resolution model, a ~19% discrepancy between different model resolutions. Calculating the amount of carbon sequestered using depths ≤1,000 m, whilst not accounting for downstream ventilation, overestimates carbon stored on 100-year timescales. This work has implications for the accuracy of more affordable and accessible methodologies to estimate the permanence of carbon storage using lower resolution models which dampen connectivity between different North Atlantic regions. Furthermore, the study highlights that the choice of location is critical for marine carbon dioxide removal deployments that require long-term sequestration in the ocean interior to be successful.

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How AERIS atmosphere Data Centre contributes to disseminate and promote greenhouse gases data

payan sébastien

AERIS / DATA TERRA, Paris, France

Theme

17. Best Practices in the landscape of Research Infrastructures: Cooperation, Co-location and other lessons learned

Abstract Text

The AERIS atmosphere Data Centre (www.aeris-data.fr), part of the French Data Terra Research Infrastructure (https://www.data-terra.org), has the objective to facilitate and enhance the use of atmospheric data, whether from satellite, aircraft, balloon, or ground observations, or from laboratory experiments. To accelerate scientific research and support collaboration between French researchers and their international colleagues, AERIS develops and implements tools and services to facilitate the sharing and use of information and data, for example in the specific field of greenhouse gases (GHG). Indeed, AERIS collects, archives and disseminates data on greenhouse gases and other related gases (such as CO for example) in the atmosphere, observed in the framework of various programs or projects. It also contributes to the production of data when processing is necessary to go from raw data to calibrated data, for example. Satellite (IASI, GOSAT, MicroCarb, …), campaigns (MAGIC, DACCIWA, …), Aircraft (SAPHIR+, IAGOS) or Balloon (HEMERA), ground measurements (ICOS-FR, TCOON-Paris, ACTRIS), Laboratory databases (GAISA, IUPAC, ECCAD), AERIS makes accessible a large set of original data, covering a wide range of geographical areas and time periods. AERIS is therefore used to provide and update greenhouse gas observation data provided by organizations or researchers offering today a vast archive of data enriched over time

This presentation of AERIS will then be focused on GHG data with a focus on tools and services implemented for related campaigns, cal/val activities, ground networks, and space mission retrieved products. Discussion on portal approach to cross use of different GHG data sets will be discussed.

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Net Zero Carbon Berlin: Developing a Systems Framework

Christopher Ryan, Galina Churkina

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Cities are increasingly being considered as important locations in relation to the specificities of their carbon (C) cycling. In addition to being sites of potential significant reductions in greenhouse gas (GHG) emissions, there is growing discourse related to cities as being places of C sequestration. As the largest city in Germany, Berlin plays a significant role in leading these endeavors. Various cities around the world have created plans for the long-term monitoring and quantification of such balances, and previous research in Berlin has similarly assessed both emissions and sequestration of GHGs, including quantifying C stocks such as in surface and subsurface soil, aboveground tree biomass, as well as sequestration potential related to construction approaches and materials. Similarly, C emission estimates for Berlin include processes related to solid waste and overall GHG emissions. The city of Berlin has a goal of achieving climate-neutrality by 2050 with on-going political agitation for moving this timeline forward. Such a transition requires a comprehensive systems approach that considers urban impacts beyond the geographical extent of municipal boundaries. This project draws from existing published data to develop a quantified schema for relevant flows and stocks of C within Berlin taking a comprehensive systems-wide perspective for achieving net zero C. This schema incorporates sectors such as energy, urban design, transportation, and industry, with practical application in the realms of biogeochemical modeling, urban planning, and policy, all of which benefit efforts in achieving goals related to climate neutrality in Berlin.

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Comparison of CO_2 Balances in Finnish Terrestrial Biosphere: Bottom-up vs. Top-down

Kielo Isomäki[1], Matthew McGrath[2], Leif Backman[1], Juha Leskinen[1], Antoine Berchet[2], Gregoire Broquet[2], Audrey Fortems-Cheiney[2], Virpi Junttila[3], Antti Leppänen[4,1], Hannakaisa Lindqvist[1], Anteneh Mengistu[1], Annikki Mäkelä[4], Maarit Raivonen[4], Laura Thölix[1], Tuula Aalto[1]

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Emissions and removals from the land use, land use change and forestry (LULUCF) sector hold significant importance to Finland's climate policy, emphasizing the need for precise tracking of carbon stock changes in the terrestrial biosphere. The reported emissions and removals from LULUCF sector in national greenhouse gas inventory (NGHGI) are subject to high uncertainty. In support of NGHGIs, independent top-down (TD) and bottom-up (BU) methods have been developed to quantify and verify CO_2 fluxes from LULUCF and associated biospheric processes.

Advancements in computation and observation methods have led to rapid progress in both BU and TD methods, with TD methods demonstrating significant potential. Rapid progress emphasizes the importance of analyzing newest available data together with its uncertainty ranges and of monitoring how methodological advancements affect the estimated total carbon balances. We consolidate existing research dataset covering large number of TD and BU estimates and contrast those against NGHGI of Finland to gain understanding of applicability of these methods in national context.

According to the national greenhouse gas inventory, biosphere in Finland removed annually on average [uncertainty range] –4.6 [-7.6 … -1.6] Mt C (of CO_2) between the years 2012 and 2020. We found consistency between TD, BU and NGHGI estimates, but large uncertainties found in BU and TD country-level balances (annual averages ranging from –49 to +32 Mt C) prohibit reliable verification of the inventory. The closest estimate was found from an ensemble of regional BU methods while the furthest estimate was provided by the regional high-resolution TD ensemble.

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Understanding the climate impacts of rewetting in a boreal peatland forest

Ellinoora Ekman[1], Kari Minkkinen[2], Anuliina Putkinen[3,4], Olli-Pekka Siira[1], Roosa Hautala[2], Angelika Kübert[1], Xuefei Li[1], Paavo Ojanen[2,5], Maarit Raivonen[1], Erkka Rinne[6], Annalea Lohila[1,6]

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

Peatlands are huge carbon storages, but due to human activities, part of this carbon is released to the atmosphere intensifying global warming. In Finland, circa half of the peatland area is drained for forestry. Drainage, together with intensive harvesting, alters water table level (WTL), and further leads to soil CO_2 emissions, especially in nutrient-rich sites. Rewetting causes CH_4 emissions but eventually the soil becomes a carbon sink again, and the accumulation of carbon will exceed the warming effect of CH_4 emissions. It is not yet fully understood how rewetting temporally affects ecosystem processes as well as carbon and greenhouse gas (GHG) balance in different peatland forest ecosystems.

A forestry-drained peatland site in Tammela, Southern Finland, is currently being rewetted. With various measurements using the eddy covariance technique, closed chambers, soil incubation experiments, water table loggers and sap flow sensors we want to understand how rewetting affects GHG-fluxes both at the ecosystem and the soil level, the surface energy balance and tree water consumption. Most of the measurements started two years ago and will be ongoing several years after the rewetting. This study will produce new knowledge about the local and global climate impacts and about the hydrological effects of rewetting in peatland forest ecosystems. Here, we present the site and the measurement set-up with some preliminary results from the ecosystem GHG flux measurements and the incubation experiments before the rewetting.

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An assessment of CO2 storage and sea-air fluxes for the Atlantic Ocean and Mediterranean Sea between 1985 and 2018.

Meike Becker[1,2], F. F. Perez[3], N. Goris[4,2], M. Gehlen[5], M. Lopez-Mozos[3], J. Tjiputra[4,2], A. Olsen[1,2], J. D. Müller[6], I. E. Huertas[7], T. T. T. Chau[5], V. Cainzos[8], A. Velo[3], G. Bernaed[5], J. Hauck[9], N. Gruber[6], R. Wanninkhof[10]

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

In this contribution we will present an assessment of carbon budgets and fluxes as well as their trends in the Atlantic Ocean. This work is part of the Regional Carbon Cycle Assessment and Processes project (RECCAP2). We compare the patterns and trends in surface ocean pCO2 and air-sea CO2 flux estimated from observation-based upscaling products (pCO2 products) and global ocean biogeochemical models (GOBMs). While they agree reasonably well in their estimates of the overall carbon uptake, we identified major uncertainties still connected to the carbon fluxes from river derived carbon, the misrepresentation of the pCO2 seasonal cycle in temperate regions in most GOBMs, and a diverging estimate of air-sea CO2 flux estimated by pCO2 products vs GOBMs. We also compare the mean accumulation rate of anthropogenic carbon, which was about 30% lower in the GOBMs than in observation based estimates.

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Multi-Year Urban Total Column Network Observations – Challenges and Insights of Using MUCCnet for Emission Estimates

Jia Chen, Moritz Makowski, Friedrich Klappenbach, Andreas Luther, Vigneshkumar Balamurugan, Josef Stauber, Florian Dietrich

Environmental Sensing and Modeling, Technical University of Munich, Munich, Germany

Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

As a large percentage of anthropogenic greenhouse gases is emitted in urban areas, accurate methods are required to monitor carbon fluxes originating from cities to mitigate climate change. To this end, we established the permanent and automated urban sensor network MUCCnet (Dietrich et al. 2021) for measuring CO_2 and CH_4 column concentrations. It consists of 5 stations inside and surrounding Munich.

The MUCCnet data showed an overall ~2.7% increase in XCO_2 and ~3% increase in XCH_4 over the last 4.5 years (09/2019-03/2024). In addition, we detected small, but noticeable gradients between the downwind and upwind stations of the city, up to 3 ppm for XCO_2 and 10 ppb for XCH_4. These downwind-upwind city gradients were inversely proportional to the wind speed. We used a mass-balance approach to infer the emissions from the gradients. The city center with many emission sources nearby was, however, not always suited as an upwind location in the mass-balance approach, which highlights the necessity of a sophisticated inverse modeling approach. In addition, we were able to validate satellite gradient measurements over Munich using MUCCnet (Rißmann et al. 2022).

For assessing urban emissions using such small signals, high accuracy and precision of the gradient measurements are required. To this end, we used Xair characteristics, e.g. slope and offset, for diagnostics of anomalies and developed a novel calibration strategy to account for drifts of pressure sensors and changes of optical properties of the EM27/SUN spectrometers. Further, different methodologies to determine the true background of the city were investigated.

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The Potential of night-time observation applications in atmospheric inversions based on CarboScope-Regional system

Yang XU[1], Michał Gałkowski[1,2], Đanilo Custódio[1], Christoph Gerbig[1]

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Inversion modelling has become a widely-used tool for the estimation of greenhouse gas emissions. This top-down approach leverages a combination of observational data and modelling techniques to reduce the uncertainties in pre-existing emission inventories. Traditionally, the application of inversion modelling has been restricted predominantly to the afternoon hours, when atmospheric conditions are generally considered well-mixed, which in turn ensures that the transport errors in models are kept to a minimum. Hence, there is a considerable untapped potential in the observational records collected at other times of the day, which could help enhance our understanding of the diurnal patterns of greenhouse gas emissions.

We have examined the vertical profiles of nocturnal meteorological parameters with data from both ICOS towers and radiosondes at nearby stations during various seasons and weather conditions, in order to assess the viability and establish criteria for utilizing nighttime carbon dioxide (CO_2) observations. To ascertain the well-mixed partial column below the tower heights, we employed an improved algorithm for retrieving nocturnal mixing layer height. We also present preliminary results from inversion runs of CarboScope-Regional (CSR) system, run over Europe for the year 2022. By implementing partial column CO_2 concentrations in CSR, we were able to obtain updated diurnal CO_2 flux fluctuations, which allowed us to assess the influence of using nighttime data on its components, specifically vegetation respiration and photosynthesis.

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Quantifying uncertainty in CO_2 air-sea exchange on the Belgian continental shelf

Tom Van Engeland, Hannelore Theetaert, Silke Verbrugge, Michiel T'Jampens, Coraline Leseurre, Thanos Gkritzalis

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

The atmosphere-ocean exchange is a critical ecosystem component in alleviating effects of anthropogenic CO_2 inputs into the atmosphere. This atmosphere-ocean CO_2 exchange is often modeled as the product of a rate constant and difference in CO_2 partial pressure. Several empirical formulations with focus on global scales exist that link the rate constant to wind speed. Using data from the ICOS station, Thornton Buoy, we investigate the contribution of this diversity in exchange rate formulations in the uncertainty in CO_2 exchange on the local scale of the Belgian continental shelf. This uncertainty is evaluated against a background of variability in factors influencing CO_2 uptake in a typical coastal marine system with river inputs.

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Micrometeorological measurements of methane and carbon dioxide emissions at landfills

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

The waste management sector accounted for almost four percent of Finland's total greenhouse gas emissions in 2022. Emissions from municipal waste disposal accounted for 80% of the emissions of the waste management sector. The percentage of methane emissions from landfills was 30% of the total anthropogenic methane emissions. The greenhouse gas emissions from landfills are mainly comprised of landfill gas, which forms when organic material decomposes anaerobically. The landfill gas consists mostly of methane and carbon dioxide. Landfilling of municipal organic waste was banned in 2014, but gas production continues for many decades. The waste treatment facilities aim to extract and collect landfill gas and utilize it, for example, in biogas, electricity or heat production.

We have been applying the micrometeorological eddy covariance method for measuring greenhouse gas emissions from landfills. With eddy covariance method, the gas exchange between the surface and atmosphere can be measured continuously. The measurements of methane and carbon dioxide emissions have been conducted in several landfill sites over the years.

With these measurements, it is possible to evaluate annual emissions from a landfill and even spot individual events, such as higher emissions due to disturbances in the gas collection system or construction work. It is also possible to combine these measurements with gas collection information and evaluate the efficiency of the gas collection system and the total methane production of the landfill (amount of collected gas and measured emission). In this presentation we show examples of the above mentioned applications from different landfill sites.

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A new wavelet-based-direct-partitioning eddy covariance CO_2 fluxes workflow evaluated in ICOS

Pedro Herig-Coimbra[1], Giacomo Nicolini[2], Carlo Trotta[2], Dario Papale[3], Benjamin Loubet[1]

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Monitoring net ecosystem exchange (NEE) between ecosystems and the atmosphere is crucial to quantifying the net biospheric CO_2 uptake worldwide. NEE is currently monitored over thousands of ecosystem sites worldwide by the Eddy Covariance method (EC). However, photosynthesis (gross primary productivity, GPP) and ecosystem respiration (Reco) are the most valuable information to understand ecosystem functioning and among the most used in remote sensing and modelling. These are currently derived from NEE by partitioning methods that involve models, most typically fitting a Reco response to temperature or GPP to solar radiation.

This study evaluates a new wavelet-based-direct-partitioning eddy covariance method proposed by Herig-Coimbra et al. (2024) on 39 ICOS ecosystem Class 1 and 2 sites, for which the raw data and all the metadata are available. The method uses wavelets to compute the NEE. It then splits positive and negative parts of the wavelet decomposed NEE conditioned by the water vapour flux to compute GPP and Reco.

Here we evaluate the robustness of the wavelet method in computing NEE and heat fluxes over the 39 ICOS sites, and compare them to the standard-EC fluxes estimates. In addition, the agreement of seasonal and monthly dynamics of GPP and Reco as estimated by the two methods are evaluated.

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From science to services: towards the Copernicus greenhouse gas emission monitoring service.

Richard Engelen[1], Anna Augusti-Panareda[2], Ernest Koffi[1], Nicolas Bousserez[1], Luca Cantarello[1], Aura Lupascu[1], Panagiotis Kountouris[1], Auke Visser[1]

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Global warming is one of the biggest issues facing the world today. Following the Paris Agreement, 195 countries have pledged to reduce their greenhouse gas emissions, but it is difficult for them to judge whether their measures are successful. As a result, a transparent system to monitor and report emissions is required.

The Copernicus Atmosphere Monitoring Service (CAMS), implemented by ECMWF on behalf of the European Commission, is being extended with a new global monitoring and verification support capacity for anthropogenic CO_2 and CH_4 emissions (CO2MVS), using the complementarity of observations and computer models. While the main focus will be on exploiting the observations from the current and future Sentinel missions, such As Sentinel-5p, Sentinel-5, and CO2M, other satellite observations will be used as well together with the increasing number of ground-based observations.

Using these observations and the Earth System modelling and data assimilation capabilities of CAMS, the new CO2MVS capacity is expected to deliver from 2026 onwards consistent and reliable information in support of informed policy- and decision-making processes, at city, national and European level.

This presentation will provide an update on the status of the implementation of the CAMS CO2MVS and especially how various EU-funded research projects, such as CoCO2, CORSO, CATRINE, and others, are contributing to the ramping up of this important initiative. Examples of specific developments and how they prepare the grounds for an operational implementation will be given.

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Complementing regional scale GHG flux observations with area-specific emission signatures.

Anastasia Gorlenko, Konstantinos Kissas, Charlotte Scheutz, Andreas Ibrom

Technical University of Denmark, Kongens-Lyngby, Denmark

Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

We are developing a regional greenhouse gas (GHG) observation system in a Danish rural area West of Copenhagen. The general aim is to quantify the emissions of an agriculture-dominated area using high-resolution micrometeorological sensors placed at different heights along a telecommunication tower. The system quantifies the surface fluxes of 4 different GHG (CO_2, CH_4, N_2O, CO) and represents sources and sinks within a 5km radius around the tower. The changing weather conditions (e.g.: wind speeds, wind directions, and atmospheric stability) favor the coverage of varying parts of the heterogeneous landscape. The multiple-gas and multiple-heights system is used to attribute the measured GHG fluxes to specific areas and processes in the landscape.

To help the interpretation of the measured GHG fluxes and ease the attribution step, we gathered information on the area around the tower. We used data from a CCTV camera to develop a traffic count and estimate the emissions coming from the roads. An inventory of the local farms and their management practices was built to estimate the emissions signatures of farmlands and crop fields. Forest and vegetation areas were characterized using a simple light response model.

We would like to present the tall tower eddy covariance system and 11 months of surface fluxes data characterizing the emissions/sinks of 4 GHG along changing seasons in a rural landscape. We would like to discuss how the bottom-up emissions modelling can help optimize the source attribution of measured GHG fluxes at a regional scale.

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Long-term monitoring of CO_2 emissions over Switzerland using observations and forward simulations of $^{14}CO_2$

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Atmospheric modelling of greenhouse gases (eg. CO_2 and CH_4) emissions is a precious tool for establishing inventories for the type and magnitude of sources at a national scale. Especially, forward modelling allows for the comparison of existing emission inventories with discrete measurements. This then allows for the refinement of said inventories in terms of source fluxes, both in a spatial and temporal way. Additionally to concentration, isotopic signatures can be added to the model to gain insight on the types of sources. For CO_2, ^{14}C in particular allows the separation between modern and fossil sources, which is crucial in the context of emission stock-taking and mitigation.

Switzerland is a densely inhabited and industrialized country in its northern half, with the Alps spanning its southern half, combining small size with high diversity of land type. Here, we study CO_2 emissions over Switzerland for a 2-year period using forward modelling of CO_2 and its isotopologues $^{14}CO_2$ and $^{13}CO_2$. Simulated results are compared to measurements taken at five sampling sites over the Swiss Plateau during the same period.

Our model aims at replicating the measured values for CO_2 and $^{14}CO_2$ by refining ecosystem respiration fluxes and isotopic values as well as the influence of Swiss and European nuclear power plants. This will provide additional constraint on the evaluation of the current Swiss national emission inventory.

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Optimizing CO2 emission estimates in Paris through enhanced urban atmospheric monitoring

Ke Che[1,2], Thomas Lauvaux[1,2], Ingrid Chanca[1], William Morrison[3], Charbel Abdallah[2], Carla Dangeli[2], Samuel Hammer[4], Andreas Christen[3], Dana Looschelders[3], Simone Kotthaus[5], Martial Haeffelin[5], Olivier Sanchez[6], Olivier Perrussel[6], Morgan Lopez[1], Philippe Ciais[1], Leonard Rivier[1], Michel Ramonet[1]

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Paris, as part of the EU-funded PAUL project (ICOS Cities), is at the forefront of cities committed to reducing CO_2 emissions. This commitment is supported by an extensive urban atmospheric monitoring network, comprising nine towers equipped with 14 high-resolution and mid-cost detectors, designed to detect significant changes in emissions. The Stochastic Time-Inverted Lagrangian Transport (STILT) model is utilized for backward runs of CO_2 enhancement from established inventories between March and September 2023. Significant reduction in transport error is achieved through the assimilation of three-dimensional wind profiles from Lidar data over Paris, employing the Weather Research and Forecasting model with Data Assimilation (WRF-DA). Three fossil fuels (TNO, Airparif and ODIAC) and three biogenic (SMURF, SMAP and offline VPRM) emission inventories are taken as priors, our inverse modeling framework utilizes an well-established Bayesian inversion technique with adaptive mesh grids (1km in the downtown gradually aggregated to 50 km across the region). This approach aims to minimize computational costs without sacrificing inversion accuracy near sites. Our results revealed notable differences in fossil fuel estimates adjustment and even greater disparities in biogenic emissions across Paris. To further validate and refine these estimates, radiocarbon(^{14}C) observations from two Parisian sites were introduced as tracers. This innovative method estimates fossil-fuel CO_2 ($ffCO_2$) based on observed 14C-CO_2 depletion relative to a clean background station, significantly improving the accuracy of distinguishing between fossil fuel and biogenic urban CO2 emissions and reducing the uncertainties in optimized emissions. Our findings emphasize the importance of leveraging a diverse array of observational sources to accurately evaluate CO2 emissions across Paris.

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The AVENGERS Horizon Europe project: Attributing and Verifying European and National Greenhouse gas and aerosol Emissions and Reconciliation with Statistical bottom-up estimates

Marko Scholze, AVENGERS Team

Lund University, Lund, Sweden

Theme

13. In situ data for climate and other environmental services and policy support

Abstract Text

The reporting of national greenhouse gas emission inventories is a crucial element in the Paris Agreement. However, the reported emissions carry susbtantial uncertainties and are lacking independent verification using the atmospheric records. The AVENGERS (Attributing and Verifying European and National Greenhouse gas and aerosol Emissions and Reconciliation with Statistical bottom-up estimates) project brings together European experts to establish top-down techniques in support of the verification of national greenhouse gas (GHG) inventories. AVENGERS will make use of atmospheric inverse modelling and data assimilation, remote sensing, environmental monitoring and observation, terrestrial ecosystem modelling, policy and stakeholder interaction together with national inventory compilers in order to improve consistency of the inventory-based GHG emission reports with top-down approaches. AVENGERS will advance the top-down approach for quantifying GHG and aerosol emissions by adding additional tracers (e.g. radiocarbon, co-emitted species, black carbon), as well as reconcile and integrate approaches into a joint bottom-up and top-down framework. Based on the reconciliation, AVENGERS will prepare good-practice guidelines for use of atmospheric inverse models as well as develop a Flexible Inversion Tool for Inventory Compilers (FIT-IC). Knowledge and outcomes are provided for policy and societal stakeholders and replicable outside of our chosen target area (Europe with a focus on Germany, Italy, Sweden, Switzerland, and The Netherlands). The uniqueness of the consortium lies in the combination of the required scientific expertise with full partner presence of official reporting agencies from exemplary EU countries facilitating the transfer of knowledge to key international organizations (such as UNFCCC, WMO) in the field.

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Methane trends at northern high latitudes estimated by atmospheric inverse modeling

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Finnish Meteorological Institute, Helsinki, Finland

Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Methane emissions at northern high latitudes have been studied using Earth Observing (EO) satellite data, in situ measurements and global atmospheric methane inversion model (CTE-CH4) estimates. Atmospheric observations from the ICOS sites and other in situ networks were used to perform atmospheric inversion model simulations to quantify natural and anthropogenic emissions over recent decades (2000-2021). Investigations of methane (CH4) sources in the northern high latitudes were extended to permafrost and non-permafrost regions, and their relationships with environmental drivers such as seasonal soil freezing, vegetation activity, precipitation and temperature were examined. Fluxes were optimized weekly to enable seasonal emission estimations, including the shoulder seasons when emissions undergo rapid changes. It was found that late summer and autumn periods showed significant increasing trends in methane emissions. Emissions were positively correlated with variables directly or indirectly related to the vegetation activity.

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ASSESSING METHANE EMISSIONS FOR MEGACITY MUMBAI, INDIA USING SATELLITE DATA

Shruti Uphale, Anurag Kandya, Viral Patel, Shubham Kela, Kaivalya Gadekar

Pandit Deendayal Energy University, Gandhinagar, India

Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

As a greenhouse gas, methane plays a critical role in climate change. Anthropogenic emission of greenhouse gases has led to a significant increase in atmospheric methane concentrations on a global scale. However, the knowledge regarding the spatial and temporal distribution of methane at a city scale is still poor. Bridging this gap, the present study puts forward the spatio-temporal variations of columnar methane concentration across Mumbai city.

The study uses the remotely sensed data generated through TROPOMI instrument aboard the Sentinel 5P satellite for a period of 4 years (January 2019 – December 2022) and presents the ward specific averages for different time periods – monthly, seasonal and annual. At a city level, the study estimates that methane has increasing at the rate of 13.48 ppb / year [1886 ppb (2019), 1900 ppb (2020), 1918 (2021) and 1925 (2022)]. The monthly average analysis reveals that the month of May (which represents a summer season) witnesses the minimum concentration of the entire year while the months of October-November (which represent a post monsoon season) witness the highest concentration of the year. The outcomes of the study would provide crucial inputs to Maharashtra Pollution Control Board for strengthening their action plan for reducing the Green House Emissions.

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Freshwater carbon fluxes at high northern latitudes

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

The high northern latitudes are characterized by a large number of waterbodies that act as carbon sources to the atmosphere in an environment that is predominantly characterized by carbon sequestration. Ongoing permafrost thawing in the warming Arctic is expected to alter the distribution of freshwater ecosystems and consequently their contribution to the overall carbon budget.
Estimates of global carbon budgets largely ignore emissions from permafrost thaw, and the carbon budgets of freshwater ecosystems are highly uncertain. A limiting factor is data scarcity in remote northern regions. In addition, the underlying processes specific to freshwater ecosystems remain poorly understood, especially given the landscape heterogeneity at high northern latitudes. To fill these gaps, we synthesize new and existing carbon dioxide (CO2) and methane (CH4) flux data from freshwater ecosystems and environmental parameters (temperature, pH, water depth, etc.) across the Arctic-boreal domain at site level and monthly resolution.
This work will contribute to the Arctic-Boreal Carbon flux synthesis (ABCflux v2), which includes terrestrial, wetland and freshwater ecosystems. We collected data from over 1,000 different freshwater sites with more than 3,000 monthly CO2 and CH4 flux measurements. With the newly synthesized data, we will quantify the carbon budgets of freshwater ecosystems across the Arctic-boreal domain and assess their contribution to the global carbon budget. In addition, the influence of environmental controls such as temperature, pH and water depth on carbon cycling processes will be investigated. This dataset will provide a unique opportunity for benchmarking and verification of process-based models and remote sensing products.

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PARIS, AVENGERS, EYE-CLIMA - Verification and reconciliation of estimates of climate forcers

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Theme

13. In situ data for climate and other environmental services and policy support

Abstract Text

PARIS, AVENGERS, and EYE-CLIMA represent initiatives funded under the EU Horizon call focused on "Verification and reconciliation of estimates of climate forcers." Drawing expertise from diverse fields such as atmospheric science, ecology, computer science, systems analysis, climate, and emissions reporting, these projects collaborate with the shared objective of refining estimates of greenhouse gas (GHG) emissions through observation-based methodologies. This collaborative effort not only aims to enhance the precision of GHG emission estimates but also facilitates meaningful exchanges with stakeholders involved in policymaking, national greenhouse gas inventories (NGHGIs), government bodies, and non-governmental organizations.

Utilising atmospheric inversion models, the three projects establish connections between surface-atmosphere GHG exchanges and atmospheric concentrations. The emissions estimates derived through this method directly correlate with atmospheric observations, remaining independent of activity data and emission factors. Consequently, this approach supports the independent verification of NGHGIs. In essence, PARIS, AVENGERS, and EYE-CLIMA strive to reconcile emissions information to contribute to the effective implementation of the Paris Agreement. Beyond atmospheric inversion methods, the projects incorporate land-surface models, which simulate the processes governing GHG exchanges between the land surface and atmosphere, along with data-driven models.

This presentation will provide a comprehensive overview of the three projects, delving into their individual objectives and highlighting the overarching efforts aimed at verifying and reconciling estimates of climate forcers.

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Recent inorganic carbon increase in a temperate estuary driven by water quality improvement and enhanced by droughts

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Theme

7. Carbon Cycling along the Land Ocean Aquatic Continuum

Abstract Text

Estuaries are an important component of the global carbon budget, facilitating carbon removal, transfer and transformation along the land-ocean continuum. A recent (1997-2020) significant increase in dissolved inorganic carbon (DIC) of 6–21 µmol kg^{-1} yr^{-1} in a temperate estuary (Elbe Estuary, DE), was driven by an increase in upper estuary particulate organic carbon (POC) of 8–14 µmol kg^{-1} yr^{-1}. The temporal POC increase was due to an improvement in water quality observed in the form of dominating autotrophy and a significant drop in BOD7. This POC increase was on the same magnitude as the DIC increase in the estuary, suggesting that POC is effectively remineralized and retained as DIC by the mid-estuary. An extensive drought period (2014–2020) modulated this trend by significantly lowering the annual mean river discharge (468 ± 234 m^3 s^{-1}) compared to the long-term mean (690 ± 441 m^3 s^{-1}, 1960–2020). During the drought period, the late spring internal DIC load in the estuary doubled. This suggests that the drought induced a longer dry season, starting in May (earlier than normal), increased the residence time in the estuary and allowed for a longer remineralization period for POC. Annually, the Elbe Estuary represents a source of inorganic carbon to the atmosphere and to the coast. Comparing the fluxes during drought and non-drought years, there was no change in the water-air flux, but a significant decrease in the lateral DIC export from the estuary during drought years, by on average 24%.

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An improved downscaling method for city-scale European GHG inventories: insights learned from comparisons with Munich, Zurich and Paris local inventories

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

High-resolution emission inventories are the cornerstone for modelling and mitigation of greenhouse gases (GHG) in urban areas. European inventories, such as CAMS-REG or TNO-GHGco, are available at up to 1km resolution and provide results with a standardized methodology. However, they require higher spatial resolution needed for urban applications.

The ICOS Cities (PAUL) project, aims to develop an integrative approach to urban measurements to better support stakeholder uptake and reach of climate targets. To develop a generic approach to making urban emissions inventories for European cities, we compared the bottom-up inventories of the cities of Zurich, Munich and Paris to spatially downscaled emissions from the TNO-GHGco inventory for GHGs (CO_2 and CH_4) and co-emitted species (CO, NO_x, BC) down to 100m scale for 12 sectors such as industry, road transport and residential combustion. A detailed comparison between these approaches is beneficial for 1) knowledge sharing 2) downscaling regional inventories for urban applications 3) supporting cities that lack the infrastructure to develop a 'bottom-up' urban inventory independently.

For each city, the TNO-GHGco inventory was downscaled using sector-specific spatial proxies such a gapfilled OpenStreetMap/OpenTransportMap vector-based data for transport emissions. Results show good agreements for spatial emission patterns in road transport and residential combustion, and less good agreements for off-road emissions due to local information on major construction sites in the bottom-up inventory. These comparisons make it possible to test and verify improvements to regional inventories.

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GHG budget estimates from polyisotopic carbon dioxide (CO_2) at Weybourne Atmospheric Observatory (WAO), north Norfolk, United Kingdom

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Polyisotopic carbon dioxide (CO_2) ratios are relatively new tools to improve our understanding of greenhouse gas cycles. We define polyisotopic elements as elements with more than one minor isotope (e.g., ^{17}O and ^{18}O next to the most abundant ^{16}O) and contrast them with polyisotopologues as compounds with two rare isotopes in the same molecule (e.g., $^{13}C^{18}O^{16}O$). Our UK Natural Environment Research Council (NERC)-funded project POLYGRAM (POLYisotopologues of GReenhouse gases: Analysis and Modelling) makes targeted observations of both kinds of polyisotopic species to quantify and analyse their meridional and temporal variations, as well as characterise source fingerprints.

CO_2 polyisotope budgets allow estimating gross primary productivity, but require leaf and soil water isotope ratios and isotopic fractionations associated with transport and uptake. Simultaneous measurements of $\delta(^{18}O)$ and $\delta(^{17}O)$ simplify these requirements since $\delta(^{17}O)$ variations are correlated with $\delta(^{18}O)$. The deviation of $\delta(^{17}O)$ from a mass-dependent correlation with $\delta(^{18}O)$ is expressed as the 'triple oxygen isotope excess', $\Delta(^{17}O)$. Variability in $\Delta(^{17}O)$ only depends weakly on the $\delta(^{18}O)$ of soil and leaf water, simplifying productivity estimates.

In this paper, we present a 2.5-year in-situ record of simultaneous $^{13}C/^{12}C$ and oxygen triple isotope (^{16}O, ^{17}O, ^{18}O) ratio measurements using an Aerodyne tuneable infrared laser direct absorption spectrometry (TILDAS) instrument at the UEA-NCAS ICOS Weybourne Atmospheric Observatory at the north Norfolk coast. Initial results gave a measurement precision of 4 ppm for $\Delta(^{17}O)$ over 30 min. We also quantify variability on seasonal and diurnal scales.

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Historic debt and future mitigation potential: How much of the greenhouse gas emissions from global palm oil production can we cut by 2050?

Alexander Röll[1,2], Najeeb A.A. Iddris[3], Michael Köhler[4], Martin Ehbrecht[5], Thomas Guillaume[6], Jens Leifeld[7], Cristina de la Rua[8], Ana Meijide[3]

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Oil palm is a major oil crop and its extent is projected to further increase. Oil palm cultivation is associated with high greenhouse gas (GHG) emissions but a comprehensive analysis of global GHG footprints is lacking. Previous studies point to differences in GHG emissions among young and mature plantations, plantations converted from forest vs. degraded land, first rotation cycle plantations vs. subsequent cycles and plantations on peat vs. mineral soils, which should be considered when assessing GHG footprints. We combine FAO data on oil palm extent and yield, age class simulations, remote sensing approaches to determine soil types and land-use origins and enhanced life cycle analysis with field-measured data to derive global past, current and future oil palm cultivation GHG footprints. The preliminary results indicate that from 1940 to 2022, the actual cumulative GHG emissions from oil palm cultivation were about four times higher than under a hypothetical sustainable land-use scenario entirely avoiding deforestation and plantations on peat. Compared to a business-as-usual scenario that assumes further growth in oil palm extent but no substantial changes in land-use management until 2050, the cumulative GHG emissions (2023 – 2050) could still be slashed substantially by smart land-use choices today, with mitigation potentials of up to

10% through sustainable intensification, up to 15% through peatland and forest moratoria for new plantations and up to 25% when additionally abandoning all existing oil palm cultivation on peat. To access these substantial mitigation potentials, a globally coordinated approach also fostering soil and biodiversity protection is needed.

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Asymmetry response of carbon and water fluxes to extreme drought in Savanna

Gnanamoorthy Palingamoorthy, Song Qinghai, Zhang Yiping

Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Xishuangbanna, China

Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

The savanna ecosystem plays a significant role in terrestrial carbon and water cycles. Climate change predicted to bring more frequent and intense droughts in the future, particularly in tropical climates. Understanding the impacts of these droughts on carbon and water fluxes in tropical savannas is essential. We studied an extreme drought event that occurred in a China's savannas in southwestern China in 2019 and used 7 years (2016–2022) of net ecosystem CO_2 exchange (NEE), and ET data to investigate the effect of the event on the ecosystem. Notably, water use efficiency (WUE) exhibited a significant increase of 41% during the drought and a 39% increase during the post-drought years when compared to the pre-drought years. This improvement was primarily driven by a 26% reduction in ET during the drought and a 21% reduction during the post-drought period. Gross primary productivity (GPP) showed insignificant changes during any of the study periods. Contrast, ecosystem respiration (Reco) decreased by 11% during the drought and 23% during the post-drought years compared to the pre-drought years, contributing to increased carbon sequestration during these periods. Overall, our results revealed an asymmetrical response of carbon and water fluxes. During the post-drought period, the carbon sink increased due to decreased Reco. However, water fluxes decreased due to limited water conditions in the ecosystem and the water-saving strategies employed by savanna ecosystems during drought events and their legacy periods. These findings offer valuable insights for understanding impact of extreme drought scenarios in savanna ecosystems.

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Using ammonia to split methane contributes of different sources in the Netherlands

Jun Zhang[1], Pim van den Bulk[1], Ilona Velzeboer[1], Harmen Manson[1], Baye Thera[1], Paula Bronsveld[1], Enrico Dammers[2], Martijn Schaap[2], Arjan Hensen[1], Daniëlle van Dinther[1], Gerrit Jan de Bruin[2]

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Theme

1. Isotopes and other tracers for studies of methane sources and sinks

Abstract Text

Only recently, the option is available to do high-frequency ammonia (NH_3) concentration measurements (at 10 Hz) with the same time resolution as methane during the mobile drive. Using an open-path NH_3 monitor (HT8700E) mounted on the roof of a TNO mobile GHG gases measurement truck, in combination with an Aerodyne TILDAS for CH_4-C_2H_6-CO-CO_2-N_2O-H_2O instrument, mobile measurements were carried out in multiple source regions in the Netherlands. We will show how different sources can be recognized and quantified using their NH_3/CH_4 ratios, similar to what we've done before with the C_2H_6/CH_4 ratio for oil and gas sources. We will demonstrate the results from various measurement campaigns in 2022, 2023 and 2024 and discuss the methane emissions from dairy, pig, poultry housing, manure application, and traffic sources in the centre of the Netherlands.

GREENHOUSE GAS FLUXES AND THEIR DRIVERS IN LARGE NORTHERN BOREAL LAKE PALLASJÄRVI

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

Due to global warming the magnitude of GHG release from high-latitude lakes is posed to increase with increasing water column temperature and shortening ice-on period. Although this is a well recognized fact, there remains numerous uncertainties in our knowledge on lake GHG fluxes.

Here, we present results based on a three year long dataset of carbon dioxide and methane fluxes collected via the eddy covariance (EC) method over a large subarctic Lake Pallasjärvi in Finnish Lapland. EC measurements are supplemented by meteorological parameters, radiation, water side measurements of pCO2, pCH4 and temperature stratification as well as flux chamber measurements. This dataset provides a look into the often overlooked aspects and drivers of lake gas fluxes: diurnal, seasonal and annual variation of fluxes, fluxes during the shoulder seasons (spring and autumn) and during the corresponding overturns of the water column and in general methane flux observations over a large subarctic lake, on which measurements from past are few and far between.

The results obtained show that the lake exhibits a large spatial as well as temporal variation in GHG fluxes. The two basins sampled show a strikingly different behavior: The deep, sparsely vegetated main basin emits very little GHG's into the atmosphere, while on the other hand the shallow, heavily vegetated basin has almost an order of magnitude higher GHG fluxes observed over the open water season.

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PARIS - PROCESS ATTRIBUTION OF REGIONAL EMISSIONS

Sylvia Walter[1], Anita Ganesan[2], Aoife Grant[2], Thomas Röckmann[3]

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Theme

13. In situ data for climate and other environmental services and policy support

Abstract Text

PARIS is a HorizonEurope research project that aims to significantly increase our knowledge about greenhouse gas emissions, the evaluation & combination of scientific approaches and a progressive use of collaborative data.

17 European partners focus on emissions of common greenhouse gases such as carbon dioxide, methane and nitrous oxide, and new emissions estimates for fluorinated gases (F-gases).

For greenhouse gases with a more complex mixture of sources, methane and carbon dioxide, research in PARIS focuses on the attribution of fluxes to particular sources and sinks. We will advance our world-leading isotopologue measurements and tracer-based analysis methods, providing inventory teams with new information to target areas of uncertainty. For nitrous oxide, a greenhouse gas for which most European inventories rely on highly simplified and uncertain bottom-up methods, two process-level models will be advanced to produce time- and space-resolved estimates that will be evaluated against isotopic data. For the important, but complex, climate forcers, organic matter aerosol and black carbon, we will take the next steps required towards robust top-down emissions inference by developing source apportionment methods. To generate maximum impact, we will synthesise our efforts in the form of draft annual Annexes to National Inventory Reports (NIRs) for eight European PARIS focus countries.

This presentation will give a general overview of the PARIS project, its objectives and implementation. It aims on introducing the project to the scientific community, presenting first results, and setting up a network for future collaborations with related projects, e.g. EYE-CLIMA (https://cordis.europa.eu/project/id/101081395) or AVENGERS (https://cordis.europa.eu/project/id/101081322).

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Europe's adaptation to the 2022-2023 energy crisis: Reshaped gas supply-transmission-consumption structures and driving factors

Chunlong Zhou[1], Biqing Zhu[1], Antoine Halff[2], Steven J Davis[3], Zhu Liu[4], SimonBen Arous[5], Simon Bowring[1], Philippe Ciais[1]

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Theme

15. Science communication and outreach to increase the impact of climate research

Abstract Text

The invasion of Ukraine by Russia in 2022 triggered a significant energy crisis in the EU27&UK. To understand how Europe adapted to this upheaval, particularly during winter months, we analyzed the pattern shifts of the natural gas supply, transmission, and consumption from the period before the invasion to after, utilizing our innovative natural gas supply-transmission-consumption models and datasets. On the supply side for the post-invasion winters, LNG imports became the largest gas supply source, rising from 21% to 31% of the total gas supply (Russian supply plummeted from 37 % to 5%). However, Russia still accounted for 41% of these LNG imports, as revealed by Automatic Identification System (AIS) data from LNG tankers. Our intra-EU gas transmission analysis highlighted adjustments made to compensate for significant gas shortages in Germany and to efficiently distribute LNG arrivals. On the consumption side, the largest reduction can be attributed to household heating behavior change (37%), such as reduced heating usage or switching to the heat pumps. In the power sector, due to the inability of boosting nuclear power, non-fossil electricity can only replace 9% of gas deficits in power generation, leaing to a figure threefold lower than our prediction. We subsequently evaluated the benefits and costs associated with these pattern changes and discussed whether these changes would potentially lead to structural changes in the EU energy dynamics. These insights can provide valuable perspectives for understanding the consequences of this energy crisis and the challenges to future energy security in the EU.

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Setting up a ground-based total column greenhouse gas measurement station in the Democratic Republic of the Congo

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

The concentration of major greenhouse gases (GHGs) in the atmosphere is steadily increasing due to emissions from anthropogenic activities. Total-column measurements of GHGs using remote-sensing techniques from ground-based and space-based platforms provide a useful tool for the quantification of GHGs in the whole atmosphere and emission source apportionment. Well-calibrated ground-based measurements are further used to calibrate and validate satellite-based measurements and to establish an indirect traceability to the WMO scale. However, to do a full evaluation of the satellite data a dense distribution of such reference measurements is required around the source-area of interest and covering an extensive range of the measurand space in terms of influencing parameters. In the framework of an ESA project Fiducial Reference Measurements for GreenHouse Gases (FRM4GHG) several portable low-spectral-resolution spectrometers were tested against reference measurements from Total Carbon Column Observing Network (TCCON) and found to be of good quality and capable of complementing the existing reference networks (TCCON & NDACC-IRWG). The low-spectral-resolution FTIRs operate under the umbrella of the COllaborative Carbon Column Observing Network (COCCON). One such low-resolution FTIR, a Bruker-Invenio, is currently in preparation for deployment at the Belgian ICOS Ecosystem site, CongoFlux in Yangambi, DR Congo, which is a data poor region. We will investigate to what extent colocation of the atmospheric and ecosystem sites will be an added value for exchange studies between the biosphere and the atmosphere.

This poster will give an overview of the project objectives, instrument set-up and deployment at the site in DR Congo and show preliminary results.

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Developing a framework for automated and continuous measurements of FAPAR from distributed wireless sensor Network

Somnath Paramanik[1], Rémi Grousset[2], Gabriele Bai[2], Christophe Lerebourg[2], Ernesto Lopez-Baeza[3], Ana Perez-hoyos[3], Alexander Knohl[4], Anne Klosterhalfen[4], Frank Tiedemann[4], Marco Clerici[5], Nadine Gobron[5], Luke Brown[6], Harry Morris[7], Jadunandan Dash[1]

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Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

The fraction of photosynthetically active radiation (FAPAR) plays a crucial role in vegetation carbon capture and dynamic vegetation models, requiring accurate and long-term observations for understanding carbon dynamics. Despite advancements in satellite-derived FAPAR products, validating their accuracy remains critical. Current in-situ validation methods, relying on handheld instruments AccuPAR, DHP, and LAI 2200, are labor-intensive and fraught with uncertainties. Conversely, distributed PAR measurements offer continuous monitoring opportunities, especially with wireless connectivity enabling remote, real-time data access and reduced logistical burdens. However, efforts to develop a standardized framework meeting satellite data validation standards have been limited. Addressing this gap, our study developed a FAPAR framework utilizing data from two wireless PAR networks: one in a vineyard site in Valencia Anchor and the other in a forest site at Hainich, as part of the Copernicus Ground-Based Observation for Validation project. Key aspects explored included developing data quality indicators, determining optimal node configurations to represent Elementary Sampling Units (ESUs), and comparing FAPAR estimation methods. At the Valencia Anchor site, 12 nodes equipped with four sensors capturing radiation at canopy top and bottom were deployed in rows. Results showed that a six-node configuration exhibited a stronger correlation ($r = 0.81$) with observed data compared to other combinations. Additionally, ESU-level 2-flux and 4-flux FAPAR displayed similar patterns with a strong correlation ($r = 0.99$), with 2-flux FAPAR performing better across different node combinations. These findings contribute to the development of a robust framework and protocol for in-situ FAPAR measurements, essential for validating global satellite-derived FAPAR products.

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Cross-scale convergence in the carbon balance of managed forests in boreal Sweden

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Boreal forests are globally important carbon (C) sinks, but strategies for maximizing their climate benefit are under debate. Major uncertainties in this discussion arise from contrasting sink-source estimates, which emanate to a large extent from the inherent limitations of standard measurement techniques to distinct spatio-temporal scales. Here, we use a spatially-nested setup of bottom-up (i.e., forest-plot inventory and chamber-based fluxes) and top-down (i.e., eddy-covariance; atmospheric observations and atmospheric transport modelling) approaches to reconcile the C balance of actively managed forests in boreal Sweden across plot-, ecosystem-, landscape-, and regional scales over 3 years (2016-2018). We find that estimates across scales converged into a C sink-strength of 118±27 g C m-2 yr-1 (mean ± 95% confidence interval). We further found greater sensitivity to the 2018 European summer drought in bottom-up compared to top-down estimates. Overall, this study consolidates the C sink-strength of managed boreal forests and advocates for cross-scale assessments to constrain forest C cycle-climate feedbacks.

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The mosaic nature of peatland emission calls for co-learning for science-based mitigation policy and community acceptance

Christian Fritz[1,2], Quint van Giersbergen[1], Tom Nijman[1], Tom Heuts[1], Ralf Aben[1], Reinder Nouta[3], Lisanne Hendriks[1], Stefan Weideveld[1,4], Bart Kruijt[5], Ralph Temmink[6]

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Theme

14. Leveraging Direct Flux Measurements Beyond Academia for Real-World Applications

Abstract Text

Regional authorities and rural communities became aware of the hot-spot nature of greenhouse gas (GHG) emission from degraded peatlands. Drainage-based agriculture and forestry on peatlands are important contributors to overall anthropogenic emission from LULUCF sectors. Interestingly, peatland emission can vary spatially by up to 3 orders of magnitudes, both on the square meter and hectare scale, challenging policy development, policy implementation and national reporting.

To foster co-learning, we created a regional GHG monitoring program in degraded peatlands in North-Netherlands. Water authorities, businesses, rural stakeholders, and conservation volunteers chose 16 dairy-grasslands and ran GHG measurements using automated chambers. Our team improved flux quality by scaling fluxes to eddy covariance and soil carbon loss data.

The regional GHG network revealed intermediate to high CO_2 emission on drained peat soils. Drainage ditches contributed large CH_4 and CO_2 emission. Subsoil irrigation/drainage (PIS/OWD) and fluctuating ditch water levels (HAKLAM) failed to reduce CO_2 emission. Effects were lacking probably because raised water tables remained below 50 cm from the surface during summer. In contrast, decreased from 250 to 85 kg CO_2 ha^{-1} day^{-1} when the water level approached the surface. Finally, emissions estimated by Tier 1 emission factors and Tier 2 national models mismatched the between-site and between-year variation found in the chamber-based estimated carbon budgets. Individual landowners, governmental representatives, and experts evaluated the measured peat soil emission using co-learning tools.

To conclude, our study showed that jointly-conducted GHG measurements creates common grounds for rural mitigation measures and improves well-informed acceptance of peatland rewetting.

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Satellite-based ocean pCO_2 estimates in the Central Mediterranean Sea and CO_2 fluxes merging satellite and insitu data

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

Insitu measurements of ocean CO_2 partial pressure (pCO_2), temperature and salinity are available at the Lampedusa Oceanographic Observatory (OO, 35.49°N, 12,47°E), in the central Mediterranean, starting from November 2021, together with ancillary quantities, including pH and chlorophyll concentration. The Lampedusa OO is in the ICOS labelling phase and the data used in this study are relative to the pre-ICOS period. The insitu pCO_2 dataset was used to develop regression models using different sets of input variables, chosen among those that can be derived from satellite observations and related to physical and biological processes affecting pCO_2. Two approaches have been used: traditional regression and machine learning, using the XGBoost model. When applied to satellite data, the best-performing multiple regression model, which uses temperature (through a linear and a quadratic term), chlorophyll, photosynthetically active radiation and wind speed as input, exhibited a mean bias of 4.4 µatm, an RMSD of 13.0 µatm, and an R^2 of 0.94. In contrast, the machine learning approach, probably impacted by the limited training dataset, performed less effectively, with a mean bias of -1.4 µatm, an RMSD of 25.0 µatm, and an R^2 of 0.76. pCO_2 values estimated from satellite data have also been used to compute CO_2 fluxes, using the Wanninkhof (2014) parameterization for the gas transfer velocity. The estimated fluxes show a fair agreement with the fluxes calculated from insitu data, with an R^2 up to 0.75.

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Evaluating greenhouse gas (GHG) emissions estimate robustness: Utilizing radon for atmospheric transport model uncertainty analysis

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Atmospheric transport model (ATM) uncertainty continues to be a significant constraining factor in making confident top-down GHG emission estimates. Currently, the selection of data for inversion frameworks relies on empirical methods, often leading to biases in data filtering due to dependence on modelled meteorological variables. As a result, a substantial portion (about 40–75%) of continuous GHG observations remains unused in emission constraints.

To address this, we propose utilizing radon measurements, a naturally occurring radioactive noble gas with well-defined source and sink. Radon's unique characteristics make it an ideal tracer to study the transport and mixing of air and thus has potential to act as an independent metric to evaluate ATM performance. A new approach involves utilising measured and modelled radon (calculated using the Met Office Numerical Atmospheric Modelling Environment (NAME) dispersion model and a radon flux map) to classify the ATM output uncertainty as either high (poor performance) or low (best performance).

To assess the effectiveness of the radon selection approach, we conducted a comparative analysis on the UK methane (CH_4) emissions sensitivity between two inverse methods, each employing different data filtering techniques. We subsequently applied the radon filtering approach to both inverse methods and quantify the differences. This will highlight the impact of filtering techniques and demonstrate the potential advantages of using radon as a tool for improving the accuracy of ATM performance assessments in GHG emission estimates.

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Net Ecosystem Exchange in a Degraded Tropical Peatland: Can restoration of degraded tropical peatlands help Indonesia achieve its carbon neutral goals?

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Theme

13. In situ data for climate and other environmental services and policy support

Abstract Text

Tropical peatlands are critical global carbon reservoirs, yet their degradation presents significant threat to global carbon balance. In Indonesia, degraded peatlands are a major source of CO_2 emissions, and efforts to restore them are central to Indonesia's ambitious carbon neutrality goals. The carbon flux dynamics following restoration therefore requires ground data monitoring. This study investigates CO_2 flux in a restoring tropical peatland in Indonesia using Eddy Covariance methods. High-frequency CO_2 flux data spanning February 2020-September 2022 were processed using EddyPro and PyFluxPro software, while meteorological variables were gap-filled using satellite data. The peatland was a small net carbon source throughout the study period, while the monthly NEE did not significantly differ between each month. There was no significant difference in NEE between wet and dry seasons. The CO_2 flux of the peatland did not correlate significantly with rainfall, likely due to higher and more controlled surface water levels maintained through this period due to adjacent canal-blocking activities and that it was a La Nina period (reduced dry season). Furthermore, the observed net CO_2 source characteristics may be attributed to the fact that extensive areas of the hydrologically-linked peat dome remain unblocked, and the adjacent rewetting only began in 2020. We conclude that while the peatland is still a net CO_2 source, it has the potential to convert to a net CO_2 sink with continuous restoration efforts. We also note the importance of a landscape-approach to restoration efforts, and that long-term monitoring, which encompasses interannual trends and baseline levels, is essential.

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The application of non-linearity calculations to greenhouse gas measurements made by cavity ring down spectroscopy.

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Theme

17. Best Practices in the landscape of Research Infrastructures: Cooperation, Co-location and other lessons learned

Abstract Text

Greenhouse gases (GHGs) are major sources of climate forcing. Since the first measurements, global networks have expanded to monitor large scale atmospheric trends. More recently there has been increasing emphasis on regional stations and networks (e.g. ICOS) to gather data on smaller scales needed for verifying international climate agreements. The development of these networks has been aided by progress in technology for higher frequency and lower maintenance measurements.

Building on previous work, the Greenhouse Gas Emissions Measurement and Modelling Advancement (GEMMA) aims at developing an emissions measurement 'dashboard' to monitor the UK's progress to net zero by 2050 target. It uses existing and additional monitoring stations.

GHG measurements were initially made using systems such as gas chromatographs (GC) flame ionisation detection (FID) for methane (CH_4). Recently cavity ring down spectroscopy (CRDS) instrumentation has been developed and their precision and stability has led to rapid uptake in the use for GHG monitoring. Here, we will show the application of non-linearity corrections used on CRDS instrumentation. We will use five NPL gravimetrically prepared synthetic reference materials which cover the atmospheric range of CH_4, CO_2, and nitrous oxide (N_2O).

Using the CRDS measurements from in-house NPL reference materials to determine the non-linearity corrections, we demonstrate their impact by applying the corrections to results from a UK monitoring site. Additionally, we produce a comprehensive uncertainty budget associated with these corrections. Our results aim to highlight the potential uncertainty introduced by this correction and consider the necessity of applying the correction to the measurements.

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Study of greenhouse gas fluxes and earth system feedbacks in the Horizon Europe project GreenFeedBack

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

The Ambition of the presented project GreenFeedBack, is to enhance knowledge of the greenhouse gas dynamics in the ecosystems and link greenhouse gases in terrestrial, freshwater and marine ecosystems to provide a solid basis for estimation of regional and global climate feedback processes taking human pressure on ecosystems into account. In GreenFeedBack we study the key processes controlling the lifecycle and fluxes of greenhouse gases in sensitive terrestrial, freshwater, coastal and marine areas of which some are hypothesized to be tipping elements in the climate system. Thus, we focus on high latitude terrestrial and freshwater systems, marine shelves and ocean areas. We use data from the ICOS stations in Europe, The SOCAT database and the GIOS, GEM and SMEAR network in Greenland and Finland as well as data from new dedicated field and laboratory studies. The enhanced knowledge will be used to improve descriptions of the GHG processes for implementation in ecosystem models and ESMs. To ensure that human activities affecting the greenhouse gas cycles will be integrated as part of the full analysis the first step in GreenFeedBack has been to identify human impact on the processes and variables relevant for driving the life cycles of the greenhouse gases in natural ecosystems.

Here we present the GreenFeedBack project, the link between the greenhouse gases in the different high latitude ecosystems, and the human pressures affecting the greenhouse gas fluxes from the natural high latitude ecosystems.

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Policy-driven mobile eddy covariance and chamber networks to monitor effectiveness of multiple emission mitigation measures in Frisian peat meadows.

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Theme

14. Leveraging Direct Flux Measurements Beyond Academia for Real-World Applications

Abstract Text

Managed grasslands on organic soils in the Netherlands, drained and used for dairy farming, are decomposing and hence emitting CO_2. Dutch government has set tight goals to reduce these emissions while the relevant provinces and water authorities bear responsibility to achieve these. There is substantial pressure to implement measures to both reduce emissions and preserve farming capacity, generally associated with elevating local ground water tables. Implementation is realised in various stages of experimentalness and scales, and it is urgent to test their effectiveness. To achieve this with direct flux measurements the challenges are both the small scale of and the large variety in measures and field conditions.

The province of Fryslân and the Frisian peat meadow programme have been proactively investing in a test scheme. Networks of flux measurement devices have been set up, including eddy covariance (EC) systems. Since mid-2021 four EC masts are deployed in pairs, rotating along sites and their associated controls for recurring one-week measurement periods. Each site is equipped with permanent observations of environmental variables as well as lateral imports and exports. The data enable both direct short-term assessment of mitigation measures versus controls and estimation of annual budgets, for which advanced machine-learning gap-fill models are developed. Results so far indicate that not all proposed measures are effective, where generally summer water tables need to be substantially elevated to reduce CO2 emissions. This monitoring network and its practical management consists a good example of how regional entities can invest in and execute direct verification themselves.

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Influence of Local Changes in Atmospheric Boundary Layer Height and Thermal Stratification on Vertical CO_2 Concentration Gradient in Lower Troposphere

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

The Vertical stability of the troposphere and the diurnal variation in the atmospheric boundary layer (ABL) height are significant factors influencing the diffusion of carbon dioxide CO_2 and other greenhouse gasses (GHGs) in the environment. Both of these factors impact whether the CO_2 concentration measurements at higher levels above ground remain significantly influenced by the local sources or the values are representative for a wider area.

To better understand CO_2 dynamics in the atmosphere depending on these two factors at the Atmospheric station Křešín (which is the part of The National Atmospheric Observatory Košetice, Czech Republic), data from continuous measurements at two levels of 250 m height tall tower were used. Furthermore, the ABL height was included, which is measured by Vaisala CL51 ceilometer at the station using the BL-VIEW software for evaluation. To determine the vertical stability, the Pasquill Atmospheric Stability Classes were calculated based on the vertical temperature gradient measured at the tower. This stability classification system divides situations into seven stability classes, with three classes being stable, one normal and three unstable.

Results of this study indicate that the magnitude of the difference in CO_2 concentration between measurements at 10 and 250 m is strongly correlated with the ABL height. However, there is no clear dependence on the ABL height for the CO_2 concentration measured at 250 m. Also the effect of vertical thermal stratification on concentrations at this level was not as significant as for measurements at the height of 10 m.

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Towards global long-term multi-tracer data assimilation estimates of carbon fluxes

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Data assimilation of atmospheric CO_2 is a powerful tool to provide global and regional carbon flux estimates. Alongside CO_2 measurements, observations of the isotope composition of CO_2 (both ^{13}C and ^{14}C) as well as atmospheric oxygen, O_2, can be used to provide additional constraints on these estimates. Each of these additional tracers have their own connection to atmospheric CO_2 through isotope or stoichiometric ratios in the underlying process leading to carbon fluxes. These couplings have been successfully exploited by passed studies. The atmospheric $^{13}C/^{12}C$ ratio is altered through different distinct isotope ratios of the underlying fluxes and has been used to quantify carbon uptake during droughts. Since ^{14}C is radioactive, fossil emission are devoid of ^{14}C, making it a good fossil fuel tracer against the modern day radiocarbon background. Then, the oxygen to nitrogen ratio has historically been used to constrain ocean fluxes, and more recently for fossil fuel emissions. The Long Window CarbonTracker Europe data assimilation system was designed to provide global and regional flux estimates at decadal to annual scales taking advantage of these records in a single multi-tracer data assimilation framework. We present the rationale of this system, along with results of atmospheric simulations with TM5 of these records and evaluate the performance of the data assimilation system against the observed global growth rate.

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Lessons learned from the labelling phase of ICOS ecosystem stations

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Theme

17. Best Practices in the landscape of Research Infrastructures: Cooperation, Co-location and other lessons learned

Abstract Text

Recent advancements in technology paved the way for extending eddy covariance (EC) measurements from local to global scales via the institution of networks of stations organised in research infrastructures (RIs). The scientific community benefits from RIs in terms of "better" data (e.g. spatial representativeness, inter-comparability), by which decision makers can rely on more accurate predictions. Participation of a station in a RI increases data quality thanks to the adherence to standardised protocols, at the cost of going through a preparatory phase (labelling), in which the station is guided by the facility appointed to ensure the compliance to the reference standards. For ICOS ecosystem stations, the labelling is coordinated by the ecosystem thematic centre (ETC) and it involves, among others, checking the location of EC measurements against topography, surface and wind characteristics, and analysing the statistical quality of the first data collected, with the purpose of maintaining quality across the network despite the heterogeneity of stations' characteristics. This presentation highlights the key aspects that deserve thorough attention when establishing new EC measurements, based on the experience gained so far. What are the site issues more often under discussion? What are the checks that discard the most, affecting data continuity? The fastidious evaluation of surface peculiarities and a proper sensors' setup are crucial, while the selection of the sensors' location should be cross-checked by footprint analysis. Non-stationarity issues are the most frequent in data cleaning. Hence, efforts to reduce the presence of gaps due to technical issues are pivotal for data continuity.

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MAGIC 2022-2023, a multi-measurement constraint on urban emissions

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Metropolitan areas are known to be anthropogenic "hot spots" of Greenhouse Gas (GHG) fluxes. To track their emission, mega-cities like Paris are currently being instrumented with dense atmospheric GHG networks, complementing the data collected by remote sensing satellites. To study medium-sized cities, where a large fraction of the global population lives, space-borne measurements often fail to quantify fossil fuel emissions since the atmospheric signatures are below the detection threshold of current instruments. For the past two years (2022 and 2023), the MAGIC campaign initiative led by CNRS and CNES (https://magic.aeris-data.fr) have been taking place in Reims, France, a city with a population of 300,000 inhabitants (207 hab./km2) located to the East of Paris (approx. 100 km away). During these two intensive measurement campaigns, a wide range of ground-based instruments have been deployed around the city to measure CO2 concentrations, in addition to instrumented balloons and aircrafts. The goal of these campaigns was to evaluate CO2 emissions from the area and to assess the detection capabilities of current satellite instruments.

In our study, we simulated the atmospheric CO2 mixing ratios using the Weather Research Forecast model coupled to a chemistry transport model (WRF-Chem) at 1-km horizontal resolution. To quantify the real fluxes, we set-up an inversion system that assimilates both in-situ and in-flight observations based on their spatial-temporal footprints, as modelled by a Lagrangian Particle Dispersion Model. Here, we present the inversion-optimized fluxes and compare them to the emission inventories of the city, along with a model-to-observation validation.

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Exploring acidification dynamics in the Southern Adriatic: Insights from high frequency pCO2 and pH data at the E2M3A observatory

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Theme

7. Carbon Cycling along the Land Ocean Aquatic Continuum

Abstract Text

An increasing amount of anthropogenic CO_2 has been absorbed by the world's oceans, leading to a process commonly known as Ocean Acidification. It has been recognised that the regulation of oceanic CO_2 uptake is controlled by the overturning circulation. Accordingly, the site of dense water in the southern Adriatic Sea could play an important role in CO_2 sequestration and contribute to the acidification of the eastern Mediterranean. In this contribution we analyse high-frequency *p*CO2 and pH data from an automatic sampling system set up on the surface buoy of the EMSO-E2M3A regional facility. E2M3A is moored in the centre of the southern Adriatic Pit and has been collecting $p\mathrm{CO_2}$ and pH data since 2015. We observe a pronounced seasonal variability in $p\mathrm{CO_2}$ and pH which highlights their correlation with temperature variations. High-frequency time series of thermohaline data measured at E2M3A and Argo floats profile are also presented. These data show that the region has undergone pronounced physical changes (increase of temperature and salinity) leading to an increased vertical mixing. Warming and salinification of the SAP could lead to significant changes in the carbonate system such as a decrease in pH and an increase in $p\mathrm{CO_2}$ throughout the water column as shown from bottle samples data from oceanographic cruises collected in the region between 2008 and 2023. Our results demonstrate the importance of an integrated oceanographic approach that combines fixed-point observations with hydrographic surveys to comprehensively investigate the response of the Adriatic Sea to climate change.

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CO2 source identification of two nearby flux towers in the city centre of Basel, Switzerland

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

The CO_2 sources of two nearby (2 km apart) flux towers in the city center of Basel, Switzerland, are analyzed with respect to traffic frequencies, heating type of buildings, vegetation and human metabolism for a period from 2009 up to date. Main differences between the two locations can be attributed to a) different traffic frequencies and b) different types of building heating. It is shown that the development and progression of district heating during the last years significantly reduces the CO_2 emissions at one station, while in the footprint of the other station, district heating was already established 15 years ago and no trend in CO_2 emissions could be observed. We also show, that wind direction patterns significantly modify the contribution of traffic to the measured CO_2 fluxes. As a conclusion we postulate to weight flux footprint contributions rather by source strengths than by land use/land cover classes.

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Assessment of float pH data quality control methods from the coupling of two observational infrastructures: A case study in the subpolar northwest Atlantic Ocean

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Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

Autonomous measurement platforms such as Biogeochemical-Argo (BGC-Argo) floats achieve continuous and independent access to the marine CO_2 system since a pH sensor has become available that is principally suitable for use on profiling platforms. This opens the possibility to detect variability and long-term changes in the interior ocean inorganic carbon storage and to quantify the ocean sink for atmospheric CO_2. From a sensor perspective, the marine CO_2 system is a particularly challenging case. This puts a high emphasis on the quality control of float-based pH measurements.

By applying current standardized adjustment routines to pH measurements from a pH/O_2 float pilot array in the subpolar North Atlantic Ocean, we assess the uncertainties and lack of objective criteria associated with the standardized routines. In our analysis, an independent assessment of the adjusted float pH data quality is presented based on crossover comparisons against discrete hydrocasts measurements and underway Ship-of-Opportunity (SOOP) pH observations. Our results point to the possibility of unacceptably high pH biases in the surface ocean which call for an additional independent reference in the surface ocean in regions with deep winter mixing.

We show evidence that a closer link between the BGC-Argo and SOOP observatories would be mutually beneficial to both networks and could potentially serve the aforementioned purpose in certain regions. Given its large synergy potential, we, therefore, propose a systematic coupling of the two observing infrastructures as they allow a better understanding of the complete water column's physical and biogeochemical variations.

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Automated transparent chamber measurements of carbon monoxide fluxes from an intensively used grassland on drained peat in the Netherlands

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Theme

2. Exchange of reactive gases and aerosols between the land surface and the atmosphere in natural and managed ecosystems

Abstract Text

Carbon monoxide (CO) forms an indirect greenhouse gas with a cumulative radiative forcing larger than that of nitrous oxide. It achieves this effect by competing for hydroxyl (OH) radicals that break down gases such as methane and ozone in the atmosphere. Incomplete combustion of fuel sources (e.g. fossil fuels, forest fires) is the major source of CO, while conversion of CO to CO_2 via reacting with OH in the atmosphere is the major removal pathway. However, CO can also be produced and removed by organisms in ecosystems, including those managed for agricultural use. Not much is known about the size of CO fluxes from these systems, their temporal dynamics, and controlling mechanisms. Here, we present data of two years of measurements with automated transparent chambers in an intensively managed grassland on drained peat in the Netherlands. At the conference, we will present annual average emission estimates, diurnal and seasonal variation patterns, and an overview of the most important drivers that include effects of management practices such as mowing and fertilization in addition to environmental conditions. Finally, we will present the potential of machine learning algorithms (Random Forest, XGBoost) for gapfilling CO fluxes.

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Characterisation of $\delta^{13}CH_4$ source signatures from methane sources in Germany with two different sampling strategies

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Theme

1. Isotopes and other tracers for studies of methane sources and sinks

Abstract Text

Determining the carbon isotopic signature ($\delta^{13}CH_4$) of different methane sources is an important tool for understanding the methane cycle and focusing on the contribution of individual sources. Changes in the atmospheric CH_4 isotope composition can be expected in the long term records, particularly as a result of the ongoing energy transition in Europe.

In this study, both direct methane source samples and samples collected in the CH_4 emission plumes were measured with a Cavity Ring-Down Spectrometer (CRDS) G2201-i (Picarro, Inc., Santa Clara, CA) to determine their isotopic $\delta^{13}CH_4$ composition. In order to obtain accurate measurement results, it is essential to characterise the instrument accurately, taking into account the possible influence of other gases like H_2O and C_2H_6. The isotopic signature of samples collected in the CH_4 plume is determined using the Keeling approach and the York fitting method.

Samples were collected from 10 biogas plants, a wastewater treatment plant, the sewage system and a cowshed. Furthermore, the isotopic $^{13}CH_4$ source signature from the Heidelberg natural gas distribution network were analysed between 2017 and 2024.

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Ammonia deposition evaluation at the ICOS Loobos site

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Theme

2. Exchange of reactive gases and aerosols between the land surface and the atmosphere in natural and managed ecosystems

Abstract Text

The Loobos ICOS level 2 ecosystem site is in the heart of the Netherlands and downwind of a major agricultural production area known as the Geldersche vallei. Since autumn 2023 ammonia deposition measurements were added to the station data set as a campaign. The role of ammonia for the total nitrogen deposition is in the order of 60 % in this area. This was estimated based on data obtained in Speuld forest tower (about 15km north of Loobos) in the episode 1985-2010 after which measurements stopped at Speuld. Now NH_3 measurements are back and both the scientific interest as well as socio economic relevance is high.We will show how that data is obtained, discuss the issues that make NH_3 observations different from the CO_2/ H_2O exchange measurements and show the levels of the deposition velocity and canopy compensation point that we have derived thusfar. We will also show the impact of the nearby agricultural area on the data and thus on the deposition at the Veluwe Natura 2000 area.

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Mixing layer heights in ICOS Pilot Cities

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Quantifying emissions based on in-situ flux measurements requires correct footprint calculations to link the fluxes measured at certain heights to their emission sources on the ground. In urban environments, heterogeneity of mechanical and thermal forcings is generally large across length-, time- and magnitude-scales. To facilitate the estimation of uncertainties within the footprint calculation, we calculated mixing layer heights using different methods, based on Doppler Wind Lidar and Radiometer Temperature profile measurements from Zürich, Munich, and Paris. We used observations of vertical and horizontal wind, temperature, and aerosol backscatter profiles to compile several different height estimates with a focus on the question, what dynamic obstacle an air-parcel might encounter first when released at the ground. Interestingly, the resulting height estimates differ greatly between different methods. We present and discuss the methods, demonstrate the differences, and suggest how to interpret these differences for applications in models and other observational techniques, such as footprint analysis or flask sampling methods.

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Carbon fluxes in marginal ice zone

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Theme

7. Carbon Cycling along the Land Ocean Aquatic Continuum

Abstract Text

Carbon fluxes in the marginal ice zone (MIZ) are important to better understand the Earth's carbon cycle, especially in the high latitude regions. This work presents the spatiotemporal distribution of the carbon fluxes in the marginal ice zone based on global numerical experiments using Nucleus for European Modelling of the Ocean (NEMO) with ORCA2.

To explore and assess the suitability of different numerical net CO2 air-sea flux parameterizations, we performed a control, a 'marginal ice zone'-off (MIZ-off) , a linear/non-linear carbon flux experiment. Each of them simulating 40 years with the respective parameterizations switched on at year 21.

Our results show both, the global and the pole-related spatial distribution of the carbon fluxes. They also show the seasonal flux distribution resolved per month. Considerable variability in both, the spatial and temporal distribution is found.

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Integration of ground and satellite datasets for the improvement of accessibility to EO resources: the OEMC project

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Theme

13. In situ data for climate and other environmental services and policy support

Abstract Text

The Open-Earth-Monitor Cyberinfrastructure (OEMC) project, funded by the European Union, aims at designing tools for increasing the accessibility of datasets in the earth observation (EO) sector. By combining in-situ measurements with space-borne datasets, the OEMC project is developing processing facilities and cybernetic resources for the interoperability and visualisation of related outcomes. The datasets used and produced must have an open licence (e.g. CC-BY) and follow the principles of the FAIRness standards. They have been organised in three Tiers, depending on their relevance, representativeness, spatial scale and other characteristics. More than 30 use cases have been identified, which represent the stakeholder interest and which are organised in monitors for specific goals. ICOS datasets included in FLUXNET are one of the eight categories of in-situ input supporting the project use cases and monitors. In addition to facilitating the users experience, the project is expected to benefit the scientific community and the whole society by enlarging the measurements coverage, reaching new and more accurate outcomes, increasing visibility, augmenting the capabilities of important entities such as the Intergovernmental Panel on Climate Change (IPCC), United Nations Framework Convention on Climate Change (UNFCCC), and other European and global bodies. We present here the OEMC project main characteristics, first outcomes, and in-situ contributions.

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The Copernicus Atmosphere Monitoring Service (CAMS) global greenhouse gases forecasts and near-real-time analysis

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

CAMS produces global daily forecasts and near real-time analysis of concentrations of CO_2 and CH_4. The procedure combines model data and satellite retrievals to create a complete and consistent dataset using ECMWF's IFS model and a 4D-Var assimilation system. The current forecast and analysis system centered on the IFS model contains the land surface model ECLand which includes Farquhar's photosynthesis model and a simple online wetland model for the simulations of CO_2 and CH_4 biogenic fluxes, respectively. Moreover, ocean flux, biomass burning, and anthropogenic emissions are prescribed for both CO_2 and CH_4. The atmospheric CH_4 sink is described using monthly mean climatological data pertinent to the CH_4 chemical loss rate in the atmosphere. Furthermore, data relevant to CH_4 sinks from the soil, and sources from termites and wild animals are also considered. To limit a potential model drift over time, optimized concentrations from CAMS global flux inversions are used as initial values at the start of each IFS system upgrade. To enhance the accuracy of the analysis, a new background error matrix has been created for each species using an ensemble data assimilation

method. The CAMS analysis (~25km) is produced with a time lag of 4 days due to the latency of satellite retrievals. The high-resolution forecast (~9km) is run separately a few hours behind real-time and relies on the analysis as initial conditions for atmospheric CO_2 and CH_4. We will demonstrate how the latest developments in the model and assimilation system have improved the analysis and forecast by comparing model simulations with independent observations.

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Time of trend detection above natural variability in cases of ocean alkalinity enhancement along the EU coastline

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Theme

8. Enhancing the ocean carbon sink: the science, verification, and governance of marine-based carbon dioxide removal (mCDR)

Abstract Text

Limiting global warming to 1.5 or 2°C now requires a portfolio of carbon dioxide removal (CDR) strategies. Ocean alkalinity enhancement (OAE) is a form of marine CDR that shows promise of being scalable and effective in the long-term. However, for it to be implemented on a large scale, there must be robust MRV to ensure responsible deployment and inform future OAE efforts. This can be done with model studies and observations, and because of financial and practical considerations, it is important to understand what can and should be observed in-situ before deploying sensors. Using models to determine the amount of data to detect a trend in biogeochemical properties above natural variability is not new (see e.g. Henson et al. 2010 and 2016, McKinley et al., 2016). However, there has been little consideration on whether this is altered in the case of OAE, where a significant perturbation to the carbonate chemistry on a localized scale can be expected. Here, we use the method of Henson et al. (2016) to assess the time of trend detection for biogeochemical properties such as DIC, alkalinity and pH in the case of continuous OAE deployment along the parts of the European coastline exposed to the North Sea/Atlantic Ocean. This is compared to a baseline run with no OAE, to understand whether the implementation of OAE impacts the length of observations necessary to detect its own influence. We do this with background emissions following SSPs 126 and 370 from 2015 until 2100.

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Traceability of $\delta^{13}C(CH_4)$ and $\delta^2H(CH_4)$ measurements from a UK tall tower site

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Theme

1. Isotopes and other tracers for studies of methane sources and sinks

Abstract Text

To achieve comparability between methane (CH_4) isotope ratio data sets, measurements must be reported on an agreed scale. The reference materials should be traceable to the international standards (Vienna Peedee Belemnite (VPDB) for $\delta^{13}C$ and Vienna Standard Mean Ocean Water (VSMOW) for δ^2H).

The majority of atmospheric $\delta^{13}C(CH_4)$ and $\delta^2H(CH_4)$ measurements have been carried out on weekly collected flask samples which are analysed via IRMS in the laboratory. The latest global inter-comparison covered only IRMS measurements and found interlaboratory discrepancies due to different calibration approaches[1]. Optical instruments are capable of autonomous operation but harmonisation of measurements for network compatible datasets is even further limited due availability of suitable reference materials and diverse methodologies for in situ calibration.

Standardised methodologies to enhance comparability of optical measurements of atmospheric $\delta^{13}C(CH_4)$ and $\delta^2H(CH_4)$ are being developed in an ongoing EURAMET project. We present analyses of $\delta^{13}C(CH_4)$ and $\delta^2H(CH_4)$ from samples collected at a UK tall tower site via a CH_4 preconcentrator coupled to a laser spectrometer[2,3]. We show how the system is calibrated using synthetic and whole-air standards (with assigned isotope ratio values traceable to VPDB and VSMOW scales). We describe the development of our long-term strategy for making traceable measurements that are compatible with other European laboratories.

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[3] Rennick, C., et al. (2021). Anal. Chem., 93, 10141-10151, doi: 10.1021/acs.analchem.1c01103

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Atmospheric monitoring of the CO_2 anthropogenic and biogenic fluxes, at European and national scales, based on the assimilation of surface and satellite observations.

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Atmospheric inversion will be the key element of the operational global and multi-scale Copernicus CO_2 monitoring service, that will support national greenhouse gas emission reporting and reduction policies. The CO2MVS inversion framework should strongly rely on satellite observations from the future CO2M missions. In the meantime, there is a need to prepare this service with the existing observation networks. This presentation summarizes results from CO_2 inversions at the scale of Europe and France carried out across several European projects. They rely on the coupling between the CHIMERE transport model at 10 to 50 km resolution and its adjoint to the variational mode of the Community Inversion Framework (CIF). The inversions assimilate, separately or jointly, observations of total column CO_2 mixing ratios from NASA's OCO-2 and surface observations of CO_2 mixing ratios. The analyses reveal i) some issues and difficulties to control the anthropogenic emissions at the national scale when using the current observation network, ii) some inconsistencies between the results obtained from the assimilation of satellite vs. surface observations at the annual to monthly scale, and iii) the challenge of deriving robust estimates of the land terrestrial fluxes at the annual scale. However, they also demonstrate some sensible and consistent patterns in the estimates of the ecosystem fluxes over long periods of time and when testing the use of different a priori flux estimates for the terrestrial ecosystem fluxes (ORCHIDEE, VPRM, CTESSEL). The assimilation of surface observations currently appears to be more robust than that of the satellite data.

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Inorganic carbon transported into the Gulf of Trieste by rivers draining karstic areas

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Theme

7. Carbon Cycling along the Land Ocean Aquatic Continuum

Abstract Text

Rivers act as important sources of carbon dioxide (CO_2) to the atmosphere, playing an important role in changing the estuarine carbonate system. Rivers and underwater springs draining carbonate watersheds deliver freshwater into the Gulf of Trieste (GoT) and contribute significantly to increasing the alkalinity in coastal waters.

The CO_2 system of the Isonzo (at the mouth) and the subterranean Timavo (at the mouth and at one underwater spring) Rivers flowing into the GoT was sampled monthly between September 2021 and December 2022 to understand the dynamics of the carbonate system (total alkalinity, pH, calcium, magnesium, strontium and $\delta^{13}C$ - DIC) at the end of the catchment and to estimate the input of alkalinity and bicarbonate into the marine system.

Both rivers were characterized by high mean alkalinities (3056-4632 µmol kg^{-1}), with higher concentrations in the Timavo system, which also showed greater weathering of calcium carbonates than the Isonzo, where the dissolution of dolomites increases the Mg:Ca molar ratio (Timavo spring 0.08±0.02, Timavo River: 0.17±0.04, Isonzo River: 0.29±0.03).

Timavo spring and River were highly enriched in pCO_2 (24182±7800 µatm and 12297±5433 µatm, respectively) and $\delta^{13}C$-DIC depleted (-13.2±0.4‰ and -11.5±0.8 ‰, respectively) due to limited degassing and degradative processes occurring in the subterranean course. Conversely lower pCO_2 (2299±1624 µatm) and higher $\delta^{13}C$-DIC (-8.6±0.8‰) values were observed in the Isonzo River. Both rivers act as a CO_2 source to the atmosphere, with a higher contribution of the Isonzo River compared to the Timavo subterranean system.

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Integrating Data into Urban Climate Governance: Interdisciplinary Approaches Through Collaborative Strategies

Barbara Dias Carneiro, Miranda Schreurs, Ana Maria Isidoro Losada, Kaayin Kee

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Theme

17. Best Practices in the landscape of Research Infrastructures: Cooperation, Co-location and other lessons learned

Abstract Text

The research presented in this paper underscores the importance of interdisciplinary collaboration, particularly within the science-policy interface, in addressing the challenges of integrating data into urban climate governance. The study, focused on the experiences of Paris, Munich, and Zurich, highlights the intricate multi-level governance structures in these cities and the interactions between stakeholders involved in shaping, sharing and implementing data into climate strategies. By employing a combination of interviews, workshops and document analysis, the research not only illuminates the increasing complexity of interactions between different stakeholders but also accentuates the importance for collaboration within the science-policy field. These collaborations extend beyond traditional relationships with higher levels of government, including intra-city collaborations and engagements with science, businesses, and civil society.

In the context of the theme of environmental issues, the paper highlights the important role of multi-stakeholder collaborations for data in climate governance. It underscores that the integration of diverse contributors within environmental research is essential for developing innovative and sustainable solutions. The challenges faced by the cities in achieving ambitious climate goals stress the urgency of bridging the gap between disciplines.

In conclusion, this research contributes to the broader discourse on interdisciplinary collaboration by highlighting the evolving nature of urban climate governance and data integration. It reaffirms the need for a comprehensive understanding of environmental problems and their solutions, emphasizing the significance of multi-stakeholder engagement in contributing positively to the attainment of climate goals. These insights align with exploring the synergy between social science and environmental research, fostering diverse discussions.

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Detection and quantification of urban methane emissions in Heidelberg (Germany) using mobile and isotope measurements

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Institute of Environmental Physics, Heidelberg University, Heidelberg, Germany

Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

The detection and quantification of urban CH_4 emissions is still a challenge due to the complex and heterogeneous distribution of emitters, i.e. leakages in the natural gas network, waste and wastewater treatment and sewerage systems. Mobile measurements at street level, using cars or bicycles, are a good way to detect methane emission sources. However, also other methods such as CH_4 flux chamber measurements (sewer system) and isotopic analysis of $^{13}CH_4$ at a local station also contribute to a better understanding of urban CH_4 sources.

In this study, we present stationary urban $^{13}CH_4$ measurements and a careful analysis of the source partitioning in Heidelberg (Germany) together with mobile CH_4 measurements at street level. CH_4 emissions from the natural gas network as well as emissions from the wastewater treatment plant were determined using a Gaussian plume model. CH_4 emissions from traffic were determined using CH_4/CO_2 rations in tunnels. CH4 flux chamber measurements were carried out at selected manholes in the sewerage system. Using our Heidelberg study as an example, we combine these approaches and compare the results with regional and global emission inventories.

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Methane emissions from rice fields in temperate environments: empirical models for estimating emissions at a local level

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Rice cultivation is one of the main anthropogenic sources of methane (CH_4). Estimating greenhouse gas emissions from rice paddies is becoming increasingly important both to evaluate the effectiveness of new agromonic management strategies to mitigate climate change, as well as to report on emission inventories at regional or national scale. These estimates are generally based on relatively accurate biogeochemical models or on more approximate global inventories. However, these approaches are hardly usable at large scales due to the large number of variables required or because they are not adequate for estimating the magnitude of emissions due to the high uncertainties.

The study aims to build a dataset, by collecting field-scale data on CH_4 emissions in temperate rice-growing areas and the main driving factors through bibliographic research, to develop an empirical model to define emissions from estimating regional-specific CH_4 emissions from paddies. Relationships between pedoclimatic variables, crop characteristics, agronomic management practices (water, crop residue, and fertilization management), and their influence on spatio-temporal variability of emissions will be investigated through different linear and non-linear multivariate models. The model, that will best explain CH4 emissions, will be further validated at farm scale by field-scale emission monitoring. This research will contribute to allowing a more accurate estimation of national inventories and to understand the potential impact of future changes in management practices and climate on CH_4 emissions from rice paddies. It will also aid in improving the adoption of climate change mitigation policies by supporting efforts to reduce CH_4 emissions from rice paddies.

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Cross-border influence: assessing the impact of additional CO_2 monitoring sites in European nations on constraining carbon fluxes in neighboring countries

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

This study employs a series of Observing System Simulation Experiments (OSSEs) utilizing the Lund University Modular Inversion Algorithm (LUMIA) inverse system to investigate the influence of an expanded European monitoring network on estimating CO_2 fluxes and associated uncertainties across neighboring countries. The focus of our expanded monitoring network is on countries in Europe lacking sufficient monitoring sites or are presumably difficult to monitor from a geographical perspective, such as Italy, Poland, Finland, and Norway. Our objective is to evaluate how the inclusion of additional sites help in constraining CO_2 fluxes within these nations and their neighboring countries. Through different OSSE sensitivity experiments, we analyze the effectiveness of reconstructing both temporal and spatial variations in these regions. Preliminary results suggest that the additional sites added in the southwest of Finland enhance the inverse system's ability to recover the seasonal cycle of the assumed true CO_2 fluxes (LPG-GUESS simulations) in the southeast of Sweden. Such enhancement is evidenced by an improved correlation between the true fluxes and the aposteriori CO_2 flux estimates (R=0.9), compared to the a posteriori flux (R=0.75) obtained with fewer sites in the south area of Finland. Here, the root mean square error (RMSE) of the true fluxes and the aposteriori also decreases from 0.56 to 0.04, and the annual CO_2 budget is recovered by 80%. This research contributes to the AVENGERS project, whose main aim is to refine greenhouse gas flux estimates at the country level to better reconcile and understand the discrepancies between bottom-up and top-down methods.

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Influence of Evaporation Gradient and Hydrologic Connectivity on Water-Carbon Dynamics in a Rewetted Peatland

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Peatland rewetting is recognized as an effective natural climate solution to reduce GHG emissions. However, rewetting often does not fully restore peatlands back to their pristine state due to irreversible changes in hydrology, geochemistry and land cover characteristics. While recent studies show that rewetted peatlands exhibit potential as effective CO_2 sinks even during drought, uncertainties persist regarding their long-term emission dynamics. This uncertainty, partly, stems from the complex interaction of biological and hydrological processes controlling ecosystem carbon balances, such as groundwater use by newly-established vegetation through evapotranspiration. Here, we use eddy covariance CO_2, CH_4 and H_2O measurements to investigate a transitional phase that currently occurring in a rewetted peatland (groundwater-fed fen) in northeastern Germany. Our long-term flux measurements indicate CO_2 source-to-sink shifts, reduced CH_4 emissions and high interannual variability in water vapor fluxes caused by water-limited conditions during drought years. Significant hydrological regime changes are characterized by high water table and progressive vegetation development. To understand the pathways of water in and out of the fen, we used dissolved organic carbon (DOC) and stable water isotopes ($\delta^{18}O$ and δD), taking spatially distributed samples. Highest DOC concentrations were from the large open-water area in our site (27±3 mg/l^{-1}) and lowest from adjacent ditches (12±5 mg/l^{-1}). This strongly correlates with heavier stable water isotopic composition in the open-water area compared to isotopically more depleted ditches ($\delta^{18}O$ average: -3.5 vs. -5.6 ‰, respectively). Continuous monitoring of site-dependent processes to identify water sources is essential for better estimates of GHG emission trajectories in rewetted systems.

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Developing a Globally Coherent MRV Framework for Marine-Based CDR: Insights and Preliminary Consensus from the SOLAS European mCDR Network.

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Theme

8. Enhancing the ocean carbon sink: the science, verification, and governance of marine-based carbon dioxide removal (mCDR)

Abstract Text

The urgency to limit global warming to below 1.5 or 2°C necessitates not only rapid and deep reductions in anthropogenic CO2 emissions but also the rapid scaling of atmospheric CO2 removal (CDR) to combat historic and residual emissions. With the ocean currently sequestering about 25% of anthropogenic CO2 emissions, marine-based Carbon Dioxide Removal (mCDR) strategies present a critical opportunity. However, the path to effectively scaling these interventions hinges on establishing robust monitoring, reporting, and verification (MRV) frameworks while considering the social and ecological risk-benefit analysis. Here, we present a European vision developed within the SOLAS network for how mCDR and its MRV could best be developed.

This abstract outlines the collaborative journey and interim findings of the European node, focusing on key MRV challenges: the timeframe for CO2 monitoring, the balance between direct measurements and modelling, the scope of MRV to include other radiative forcing processes(GHGs, aerosols, etc), data transparency, managing residual uncertainty, verification mechanisms, and identifying overseeing bodies. Our efforts aim to converge on a "satisfactory, yet achievable" MRV paradigm that ensures credibility without stifling innovation, thereby addressing the specific MRV challenges faced by the European node.

The consensus reflects diverse European views but emphasizes a united effort towards a practical, globally acceptable MRV framework. Ensuring MRV accuracy is pivotal for assessing ecological impacts and securing mCDR safety. Our findings contribute to a policy brief for ethical mCDR deployment worldwide, showcasing practicality and international agreement.

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Bridging the gap between historical and ICOS ecosystem flux data series: methodological choices and their impact on net fluxes

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Long-term flux data series are at the heart of ICOS research infrastructure, and multiple ecosystem ICOS stations are highly valued for their historical dataset, which extends years before the ICOS collection. However, instrumental and methodological innovation has led to potential differences in computed turbulent net fluxes, which can result in discontinuities in the datasets. We worked on quantifying the differences between the custom PI-processed historical data and the standardised ICOS-processed data, caused by changes in methodology only. We focused on the spectral correction, as it appeared to be the main cause behind the divergences. The resulting analysis highlighted that the use of certain default options in the ICOS processing pipeline might not be suitable for all site typologies. An example is the denoising of spectra, which is shown to potentially remove true signal, thus inducing artificially high correction factors especially for sites measuring close to the canopy, as their spectral content shifts towards the high frequencies. Once different processing options have been aligned, a more fundamental question, regarding the choice of using spectra rather than co-spectra when performing the correction procedure, is investigated. The effects of both choices are assessed. These findings open the way to possible refinements in the standard ICOS flux processing methodology, and potentially in the widely used flux calculation software.

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Influence of karstic rivers and southern Adriatic waters on the CO_2 system of the Gulf of Trieste (Mediterranean Sea)

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Theme

7. Carbon Cycling along the Land Ocean Aquatic Continuum

Abstract Text

The carbon cycle in coastal areas is particularly dynamic due to the complex interactions between different carbon sources and sinks.

The present study focuses on the influence of carbonate aquifers on the CO_2 system in the Gulf of Trieste (GoT, northeast Adriatic Sea). Three marine stations (in the north, centre and south GoT) were investigated monthly between September 2021 and December 2022 at 4 different depths for key water chemistry and carbonate system parameters.

In the surface waters under the influence of river water, total alkalinity was highest (2728±19 µmol kg_{sw}^{-1}), pCO_2 was 425±35 µatm and δ^{13}C-DIC was 0.66±0.39 ‰. Total alkalinity (TA) was inversely correlated with salinity, indicating a high contribution of bicarbonates and carbonates from river discharges.

The highest pCO_2 (594±68 µatm) and the lowest pH (7.951±0.040) and δ^{13}C-DIC (0.61±0.35‰) occurred in bottom water isolated below the pycnocline during summer/early fall, reflecting the contribution of respiration and decomposition processes.

The Eastern Adriatic Current brings southern waters with increasingly high salinity into the GoT, which when they cool in winter, form very dense water (1029.7±0.2 kg m^{-3}) with a high TCO_2 content (2401±24 µmol kg^{-1}). These southward-flowing waters contribute to the formation of the Eastern Mediterranean Deep Water.

The observed low river discharges amplified the effect of the intrusion of high salinity waters with a lower buffer capacity. A future increase in prolonged droughts could therefore, reduce the buffering capacity of GoT.

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An innovative use of eddy covariance methodology to assess energy, water and carbon fluxes over utility-scale photovoltaic parks in France.

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Theme

14. Leveraging Direct Flux Measurements Beyond Academia for Real-World Applications

Abstract Text

Ground-mounted solar power plant projects are under pressure for diverse reasons, including the lack of available lands, conflicts of use, or the uncertainty on their environmental impacts. They are preferably installed on artificial surfaces, but also deployed in agricultural or forest areas.

In order to improve our understanding of the biophysical processes involved in matter, heat and energy transfers in the solar park surface-atmosphere continuum, energy balance, fluxes of water vapour and carbon dioxide have been monitored on an industrial brownfield nearby Caen (France), converted into a 19ha solar park characterized by partial sealed soil covered with scattered vegetation. Eddy covariance methodology (EC) is commonly used in grasslands, croplands and forests, but is rarely deployed over urban systems. Since January 2023, an EC system, combined with meteorological and edaphic measurements has been applied successfully on this ecosystem.

The analyses showed a dominance of sensible heat flux over latent heat flux all along the measuring period. This observation could be linked to the potential heating of the air above the park, by the surface of panels and the minor role of vegetation. Carbon exchanges were particularly sensitive to the meteorology, more than to vegetation management. The annual carbon balance was slightly negative. These on-going measurements, compared with another solar park near Bordeaux, in place of a pine forest, will help solar plants owners in designing their park to potentially improve their environmental impacts such as minimising the heat flux emitted, optimising carbon storage, and minimising the negative impacts on biodiversity.

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Towards a more reliable GPP estimation: A systematic assessment of using the photochemical reflectance index as a proxy for non-photochemical quenching

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

Closing the terrestrial CO2 budget on a global scale remains challenging, with significant implications for policymaking to meet internationally agreed emissions goals. Remote sensing of solar-induced chlorophyll fluorescence (SIF) holds promise for more accurately assessing gross primary productivity (GPP) globally. Fully exploring this potential, for example by matching flux tower footprints with remote sensing data, is only informative to some extent as current satellite missions lack adequate spectral, spatial, or temporal resolution. However, this gap is expected to be addressed by the upcoming Fluorescence Explorer (FLEX) mission by the European Space Agency (ESA).

Besides these technical challenges, understanding the relationship between SIF and GPP under varying environmental conditions remains elusive through remote sensing alone. This is because a third process, non-photochemical quenching (NPQ), competes for the same energy pool. This is especially relevant during periods of vegetation stress caused by increasingly frequent extreme weather events. While previous studies have used the photochemical reflectance index (PRI) as a proxy for NPQ on a case study basis, a systematic assessment across ecosystems and environmental conditions is lacking. In this contribution, we address this gap by systematically assessing the relationship between SIF and GPP using a unique dataset collected from seven European flux tower sites over the period of 2018-2022.

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CO_2, Surface Radiation, and Meteorological Outcomes in the Polar Regions

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

According to the IPCC, "The Earth's radiation budget is a central element of the climate system. ….Anthropogenic influence on climate occurs primarily through perturbations of the components of the Earth radiation budget." Unfortunately, the estimated consequences of CO2 have largely ignored the components of this budget. It is, therefore, not surprising that some researchers have been unable to reject the null hypothesis of natural variability as a driver of rising temperatures.

This paper represents an attempt to address this gap in the research using hourly CO2 and meteorological data. The following surface radiation variables are also employed in the analysis: downward short-wave, downward long-wave, upward short-wave, and upward long-wave. The data set spans from Jan 1, 1998, through Dec 31, 2022. The analysis employs data from the Barrow Atmospheric Observatory in Alaska, the Ny-Ålesund Observatory on the island of Svalbard, the South Pole Observatory, and the Neumayer Observatory in Antarctica.

The relationships among the variables are addressed using the concept known as Granger Causality. Granger causality is based on whether the lagged values of some variable X are useful in predicting the current value of some variable Y. The analysis proceeds by employing the vector autoregressive regression method, in which all of the contemporaneous values of the variables are endogenous. One of the more basic findings is that CO2 concentrations have Granger Causality consequences for surface radiation and meteorology in both polar regions.

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Eddy Covariance and Chamber Flux Measurements in a Peatland in Portugal within EU funded REWET project

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Theme

14. Leveraging Direct Flux Measurements Beyond Academia for Real-World Applications

Abstract Text

Paúl da Gouxa lowland peatland (Alpiarça) is a recently established nature reserve with 140 ha and 9 meters of peat in some areas. Since March 2024 flux measurements are being monitored continuously with an eddy covariance (EC) system installed in a 10 meters tower. Complementarily, chamber measurements are being performed in the footprint of the EC tower over water, soil and willow trees. Preliminary results of the calculated fluxes are presented and an evaluation of the stored/released carbon and methane are discussed in light of the projection of future Carbon dynamics according to different management practices and climate scenarios. We conclude with the recommendations on the most appropriate sustainable practices and land management strategies to address climate change challenges and protect biodiversity. This research was funded by the European Union trough REWET project: Restoration of wetlands to minimize emissions and maximise carbon uptake – A strategy for long term climate mitigation. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them. The authors acknowledge the project SOLVIT (C644866286-011) PRR – Agendas Mobilizadoras.

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Gaussian Inversions of Natural Gas Fluxes from Super-Emitting Orphan Wells with Ambient Ground & UAV Observations to Prioritize Plugging

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Theme

1. Isotopes and other tracers for studies of methane sources and sinks

Abstract Text

Orphan-wells are targeted for plugging with $4.7B under Bipartisan-Infrastructure-Law to reduce the 2.6 Tg/year methane-CH_4 emitted from >3.6M abandoned-wells in the US. Current methods to quantify natural gas-CH_4/C_2H_6 emissions are cost-prohibitive, time-consuming, unsafe, and/or inaccurate. We evaluate a simple method to estimate emissions from orphan wells using ambient *in situ* ground and UAS-based measurements of CH_4/C_2H_6 and winds. Field observations were performed downwind of a super-emitting orphan well prioritized for plugging. We used our CH_4 and winds data downwind from the well to constrain the stability parameters of a gaussian model and infer fluxes. CH_4 increases synchronously when the winds are aligned with our samplers and decreases with distance from the well. Our gaussian-derived emission rate of 6–12Kg CH_4 h^{-1}, uncertain to ±33%, agrees with directly measured volumetric flowrate of 9.0±0.25Kg CH_4 h^{-1}. Our observed leak rate is 41% greater than was measured earlier and is attributed to the reservoir pressure buildup from closing the vent valve to contain the leak. We also discovered a surface-casing leak that is inferred to be 0.4–0.7Kg CH_4 h^{-1} consistent with aerial data. Our method accurately quantifies fugitive leaks from super-emitting orphan wells(~10Kg h^{-1}) that account for a small fraction (10%) but contribute the most to net CH_4 fluxes(>90%). As part of US-DOE's-CATALOG project, we have developed a strategy integrates wide area survey of CH_4/C_2H_6 from UAVs to identify leaky wells and fast ambient flux observations of fluxes from high-emitters to prioritize well plugging and maximize CH_4 reduction.

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"Urban Greenhouse Gas Emissions in Uganda: Unveiling Hidden Sources for Sustainable Development"

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Background

With Uganda's urban areas experiencing rapid growth, understanding and mitigating greenhouse gas (GHG) emissions are critical for sustainable development. However, identifying emission sources remains a challenge.

Objective

This study aims to uncover and quantify urban GHG emissions in Uganda, employing innovative monitoring methods and pinpointing key emission sources crucial for sustainable urban planning.

Methods

Using cutting-edge technologies and tailored methodologies, this research quantifies GHG emissions in Ugandan cities. Spatial analysis and advanced modeling techniques unveil emission patterns and distribution, while source identification methods shed light on major contributors.

Results

Findings reveal the extent and spatial distribution of urban GHG emissions, emphasizing critical sources such as transportation, energy use, industries, and waste management. Insights provide valuable data for policymakers and urban planners.

Conclusion

Understanding and addressing urban GHG emissions are essential for Uganda's sustainable development journey. By unraveling hidden emission sources, this study contributes to evidence-based decision-making and fosters sustainable urban development in Uganda.

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Power of philosophy *Alli kawsay (Buen Vivir)* in indigenous movements of Colombia - Ecuador, contribution to the Rights of Mother Nature from the global south in middle of climate change

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

The purpose of this research is to present the urgency of listening to indigenous epistemologies of *Sumak Kawsay* (in *kichwa* language: *Buen vivir*-Good Living) and also to accompany the care/defense of the biodiversity-rich indigenous territories of the Andean region. As a research question: How is the anthropocene affecting the indigenous territories and with it the threats of the epistemologies of *the Sumak Kawsay/Buen vivir*?

This ethnographic research has been carried in the last 7 years, in Republics of Colombia and Ecuador, in Indigenous Regional Council of Cauca CRIC, and The Indigenous Confederation of Ecuador CONAIE. Theoretical references: epistemology of indigenous communities, indigenous intellectuals. The anthropocene affects considerably the species of flora and fauna, the glaciers, water reserves, páramos understood as places where the water is born for the species. With it the territories Pan Amazonas region of native communities are strongly affected in their cosmovision to know.

Due to its high impact in high mountain areas, climate change affects the melting of glaciers, strong droughts, seasonal changes for food production, water shortages and with this the displacement of animals and indigenous people and with it affects their traditions and cosmovisions due to geographical relocation and spatial - socio-cultural changes.

Ethnographic work is used: interviews, participant observation, and documentary analysis. Key to comment how from the epistemologies, their spirituality's, indigenous cosmovision, the elders (grandparents and grandmothers) announce that if there is no respect for the species on earth comes catastrophe, which from modern science is already evident.

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Examining high temporal variations in greenhouse gas emissions at an urban site in India using CH_4/CO, CH_4/CO_2, and CO/CO_2 correlations observed during 2016-2023

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Greenhouse gas (GHG) emissions have escalated in recent decades in India mainly due to economic development, increased anthropogenic emissions, high energy demand, etc. Various studies have attempted to understand carbon variations in India at different time scales by using models and observations. Most studies focus on either using background, rural observations, or remote sensing techniques. There is a scarcity of studies specifically focusing on observing greenhouse gas (GHG) in urban locations in India. Urban sites are mainly influenced by local emissions and emissions transported through long-range seasonal airmass transport. Also, such sites are crucial for validating model simulations at mesoscale resolution. An in situ GHG observation site was established in an urban environment, Pune, located at the western boundary of India. In this study, we present atmospheric CO_2, CH_4, and CO concentrations observed using the Picarro G2401 instrument at a high temporal frequency during 2016-2022 in Pune, India. Systematic calibration was done using NOAA standards. The ratio of $\Delta CH_4/\Delta CO$, $\Delta CH_4/\Delta CO_2$, and $\Delta CO/\Delta CO_2$ concentration residuals shows high values during monsoon (1.09±1.25, r=0.64), winter (15.51±91.54, r=0.47), and post-monsoon (64.15±1513.85, r=0.046) seasons respectively. Using these observations and correlations between CO_2, CH_4, and CO, we have examined how these gases emission sources influence each other at diurnal to seasonal scales and through local emissions to long-range airmass transport. CH_4/CO, CH_4/CO_2, and CO/CO_2 concentration residuals correlate significantly high during pre-monsoon months with r=0.71, 0.62, and 0.39, respectively. The pre-monsoon season exhibits the strongest correlations among these greenhouse gases.

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Participatory hydrological modelling for collective exploration of catchment management: promoting water stewardship across a multi-stakeholder platform

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Theme

15. Science communication and outreach to increase the impact of climate research

Abstract Text

Increasing water scarcity and growing water demands have led to policies focused on collective catchment management to deal with rising issues. There is a critical need to find ways to promote effective water stewardship across a multi-stakeholder platform, to ensure socially and environmentally acceptable ways of securing and sharing the resources. This project aimed at fostering social learning and group decision-making about catchment management in Kouga and Kromme catchments of South Africa by using a participatory approach to develop models of local hydrology. Stakeholders identified potential land and water management, and climate scenarios to explore and evaluate likely hydrological and socio-economic outcomes. The long-term goal was to develop a shared understanding of the social-ecological systems and build trust relationships, working towards a common vision of catchment management. Several engagement tools such as dialogue interviews, workshops and learning journeys were used to collectively explore issues. Potential changes described by stakeholders were converted into alternative climate and land cover maps using assumptions about potential spatial distributions of different cover types and changes in climate patterns.

During stakeholder engagements, three levels of social learning were evident: cognitive (knowledge-based), affective (emotion-based) and behavioral (action-based). Different engagements and tools provided different insights feeding into the model and scenario development. A framework was developed based on the Theory U, which provides several tools useful for engagement with diverse stakeholder groups, addressing social dynamics in a shared-space for learning. This project highlighted the critical need for collective stakeholder engagement in catchment management.

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Land-Atmosphere Exchanges in Complex Urban Landscapes: From Process Diagnosis to Climate Impacts

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Understanding urban climate, air quality and greenhouse gas budgets relies heavily on high-quality observations of urban surface interacting with its overlying atmosphere. This research need has motivated increasing interest in urban eddy covariance flux measurements across cities. We present the findings of a workshop supported by the Department of Energy's Office of Science held at Argonne National Laboratory November 13-14th, 2023, that focused on knowledge gaps and research needs concerning flux measurements and their applications in complex urban landscapes.

We summarize the findings from four thematic groups. First, we review progress and challenges in conducting eddy covariance flux measurements in urban areas, including issues related to deployment strategies, sensor platforms, data processing and source decomposition. Second, we describe the site descriptors and ancillary data required for heterogeneous urban areas and

the need for standardized approaches that enable intra- and inter-city comparisons. Third, we review urban land-atmosphere flux models and place these in the context of how models can be parameterized and improved using flux datasets complemented with appropriate ancillary data and site descriptors. Finally, we discuss how eddy covariance studies can aid in impact, adaptation and mitigation studies in urban areas.

We illustrate these issues with examples from our research community and present an overview of the growth of urban eddy covariance flux measurements and their applications. We set forth an agenda for community development moving forward, with attention to early career investigators and investigators from regions that are underrepresented in the global eddy covariance flux measurement network.

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Inferring summertime CH4 surface flux from atmospheric boundary layer concentration measurements at the Zotino Tall Tower Observatory (ZOTTO).

Dieu Anh Tran[1,2], Ingrid Luijkx[2], Jordi Vilà-Guerau de Arellano[2], Santiago Botía[1], Christoph Gerbig[1], Raquel González-Armas[2], Wouter Peter[2], Sönke Zaehle[1]

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Theme

1. Isotopes and other tracers for studies of methane sources and sinks

Abstract Text

The eddy covariance technique allows for direct methane flux measurements through high-frequency operations of atmospheric turbulences. But while several tens of stations are in service in the North American boreal zone, the Siberian region is only sparsely covered by such measurements. In Siberia, the predominant way to determine CH_4 fluxes has been by chamber measurements. This motivates the exploitation of existing data sets in Siberia to gain spatially and temporally better-resolved carbon budgets. The ZOtino Tall Tower Observatory (ZOTTO; 60° 48′ N, 89° 21′ E) observations of CH_4 mole fractions, as well as meteorological parameters from six different heights up to 301 m a.g.l, allow for an additional estimate of surface-atmosphere fluxes of CH_4 for the middle Siberian region since beginning 2009. We will apply a complementary approach to infer CH_4 surface flux – the mixed-layer theory. The theory is based on boundary layer budget methods valid under convective conditions. Under these conditions, we can assume that well-mixed conditions prevail a mixed-layer value of CH_4 that is representative of the entire boundary layer, and relatively small differences in the regions with concentration gradients (above the canopy and in the entrainment zone) are used to estimate CH_4 fluxes on local scales. We will compare trends and interannual fluctuations in the inferred CH_4 fluxes with STILT-simulated regional CH_4 fluxes to understand the contribution of local influence on the regional signals.

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Visualizing science: an immersive technology in education and science communication

Dmitrii Krasnov, Steffen Manfred Noe

Estonian University of Life Sciences, Tartu, Estonia

Theme

15. Science communication and outreach to increase the impact of climate research

Abstract Text

The constant development of computing, information, and multimedia technology enables new methods of visualising and delivering science-related information in science communication and education. A virtual tour (VT) as part of virtual reality (VR) could be an example of such progress. VT offers a unique storytelling approach, enabling multiple perspectives and representations of content. VT typically consist of logically organised 360-degree photography and might have integrated 3D models, videos, audio, textual, and graphical information. It offers a fully interactive environment, allowing users to explore it at their own pace and utilise diverse media devices, including smartphones, PCs, headsets, and specialised classrooms equipped with 360 screens or CAVES. The same VT could be adapted to different target groups. For technicians, for example, customised VTs can include technical details, photos, videos, 3D objects, and documentation, accessible at any time. Many social media platforms and specialised web hosting services support the integration of VR content for entertainment and education. These services could be used to reach different target groups (general public, non-experts, etc.), especially since the VT content could be fully customised to a particular publishing platform and groups.

This presentation will illustrate the potential applications of VTs in science, education, and science communication using SMEAR Estonia VT (https://smear.emu.ee/visuals/SMEAR/) as an example. It will also demonstrate the process of developing, utilising, and maintaining VTs. The discussion will cover technological advantages and disadvantages, available software and hardware, multimedia integration, publishing platforms, and generative AI. Special attention will be dedicated to the development of immersive training tools for technicians, scientists, and students.

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Simulation of carbonyl sulfide and carbon dioxide fluxes in a northern boreal coniferous forest using memory-based deep learning

shuai liu[1], Wei He[2,3], Peipei Xu[1], Mengyao Zhao[1], Chengcheng Huang[4]

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

The northern boreal forests, which is sensitive to global warming, serve as critical terrestrial carbon sinks. Accurate monitoring of boreal forest carbon dynamic is of great significance, but considerable uncertainties still exist. As a pioneer study for guiding mechanistic simulations, this study explores the potential of Long Short-Term Memory networks for carbonyl sulfide (COS) and CO_2 flux predictions and disentangles their controlling factors across temporal scales with eddy-covariance flux data in a northern coniferous forest in Finland from 2013 through 2017.

The results indicate that the model's predictive performances for COS, GPP, and NEE vary substantially across different time scales. At a half-hour scale, the model predicts COS, GPP, and NEE with R^2 of 0.51, 0.62, and 0.75, respectively, and RMSE of 7.78, 3.51, and 2.08 μmol m^{-2} s^{-1}, respectively. However, the predictive performance significantly weakens at 3-hour or 6-hour scales. For the latter, the model predicts COS, GPP, and NEE with R^2 of 0.23, 0.20, and 0.17, respectively. Yet, at a daily scale, the performance improves significantly; it further strengthens at a weekly scale, with R^2 of 0.87, 0.81, and 0.58 for them, respectively. Moreover, the major factors affecting COS and CO_2 fluxes differ clearly across time scales. At shorter scales, photosynthetically active radiation is a predominant factor, while at longer scales, soil temperature and moisture are more predominant. We will further investigate the interplay between COS and CO_2 fluxes across scales. These findings provide important clues for the mechanistic simulation of carbon fluxes in northern boreal forests.

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Water use efficiency of a pine forest exceeds that of a mixed forest in boreal Sweden

Alisa Krasnova[1], Anne Klosterhalfen[2], Peng Zhao[3], Jinshu Chi[3], Dmitrii Krasnov[4], Hjalmar Laudon[1], Mats Nilsson[1], Matthias Peichl[1]

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

Ecosystem water use efficiency (WUE) is a key ecophysiological characteristic that quantifies the coupling of carbon and water fluxes. It can serve as an indicator of the ecosystem ability to manage the trade-off between carbon gain and water loss under varying climatic conditions and extreme weather events. Although the study of ecosystem WUE in young plantations is extensive, research comparing the WUE of mature stands with diverse tree species compositions, particularly in the boreal zone, is notably scarce.

The aim of our study was to compare the WUE of two mature (100-110 y.o.) coniferous forests, typical for the boreal zone of Northern Sweden. The Svartberget site is a mixed forest stand comprised of pine (*Pinus sylvestris*, 61%), spruce (*Picea abies*, 34%), and birch (*Betula sp.*, 5%) species; the Rosinedalsheden site is a pine (*Pinus sylvestris*) forest stand. Given their proximity, both sites are subjected to similar meteorological conditions.

Across all years in our study (2015-2020), the mixed forest displayed higher rates of carbon uptake and water loss, yet exhibited lower ecosystem and canopy WUE compared to the pine forest. Under conditions of atmospheric drought, both sites saw an increase in canopy WUE, with the pine forest showing a significantly more pronounced response.

Our work contributes to the limited body of research on mature boreal forest WUE, highlighting the importance of tree species composition in forest adaptability to climate variability and extreme weather events.

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Vineyard floor vegetation defines net CO_2 exchange during the crop dormant season

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Analyses of CO_2 net ecosystem exchange (NEE) dynamics of perennial fruit crops provide a baseline understanding of these ecosystems and how they are impacted by management. However, most studies focus on the growing season, overlooking the winter dormant period which may impact the net annual carbon balance. Although soil respiration often dominates in this season, the presence of cold-resistant floor vegetation may partially mitigate the efflux. CO_2 fluxes were monitored over a grassed mountain vineyard in South Tyrol, Italy, by eddy covariance with the addition of clear and opaque ground flux chambers from 22nd January - 7th March 2024 due to unsuitable turbulence conditions. Photosynthesis occurred during the day owing to favourable sun exposure, lack of snow cover and >0° C temperatures, increasing with floor vegetation growth. This exceeded the ground respiration (R_{grnd} = 122 g C m^{-2}, including soil and herbaceous vegetation) by a total of 17 g C m^{-2} over the measurement period. The total NEE estimated by eddy covariance during the preceding grapevine growing season (15th April – 15th October 2023) was - 236 g C m^{-2}. The chamber-based NEE, which did not cover the entire winter season, therefore accounted for an increase of 7% in C sequestration. While this represents a moderate increase, the mitigated heterotrophic respiration over this period ($R_{heterotrophic} \approx 0.5*R_{grnd}$) was 26% of growing season NEE, representing the CO_2 loss over bare soil. Farmers should therefore be encouraged to maximise floor vegetation biomass during the crop dormant period to improve annual carbon balance.

420

Urban CO_2 and CH_4 atmospheric measurements in the Milan city area (northern Italy)

Paolo Cristofanelli[1], Nora Zannoni[1], Alessandro Bracci[2], Francescopiero Calzolari[1], Luca Diliberto[2], Cecilia Magnani[1], Valeria Mardonez[1], Camilla Perfetti[3,1], Laura Renzi[1], Angela Marinoni[1]

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Northern Italy is one of the most polluted and densely populated areas in Europe. This region is an important contributor to greenhouse gas emissions from different sources: medium and large cities, as well as industrialised areas, contribute significantly to emissions from industrial processes, combustion, waste management and natural gas distribution.

As part of the H2020 RI-URBANS project (https://riurbans.eu/) and in synergy with PNRR ITINERIS Project, a pilot study has been carried out in the Milan urban area with the aim of supporting the local authorities to evaluate the effectiveness of air quality policies and the effects of pollutants on human health. A one-year long measurement campaign was carried out using a mobile platform in the premises of the CNR facility (AdRMi1, 45°28’47"N 9°13’54"E; 120 m a.s.l.), located in in the University district. The mobile platform has been equipped with a suite of instruments (ACSM, Vocus Chemical Ionization TOF-MS, Aethalometer, NOx CLD). From July 2023 to March 2024, the mobile platform has been equipped with a Cavity Ring Down Analyser for continuous observations of carbon dioxide (CO_2) and methane (CH_4).

In this work, we will provide a first characterisation of the diel cycles and seasonal variations (from late summer to early spring) of atmospheric CO_2 and CH_4 in the urban area of Milan. Thanks to the combined analysis of other atmospheric tracers, first insights about the influence by atmospheric processes (i.e. PBL dynamics) and emission categories will also be discussed.

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The need to develop ocean-based carbon dioxide removal in a globally fair and equitable manner: Perspectives, principles and recommendations

Christopher Pearce[1], Zeynep Clulow[2], Rob Bellamy[3], Habiba Ahut Daggash[4], Paul Halloran[5], Duncan McLaren[6], Sarah Reynolds[7], Chris Vivian[8], Phillip Williamson[9], Joo-Eun Yoon[2,10]

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Theme

8. Enhancing the ocean carbon sink: the science, verification, and governance of marine-based carbon dioxide removal (mCDR)

Abstract Text

Marine Carbon Dioxide Removal (mCDR) approaches have the potential to play a significant role supporting the transition towards a climate neutral and climate resilient society. Whilst many projects are currently seeking to enhance our scientific understanding of, and ability to monitor, the efficacy, durability, scalability and co-benefits/risks of each technique, less consideration is being given to developing mechanisms for ensuring the fair and equitable distribution of the costs and benefits of mCDR.

Understanding where and how mCDR is likely to be implemented is of critical importance when considering the governance mechanisms that will be required and perceived as socially acceptable, which will ultimately shape the true scalability potential of each technique. In addition, many mCDR approaches are premised on developments and deployment scenarios within advanced economic contexts, yet the large marine Exclusive Economic Zones (EEZs) of Small Island Developing States (SIDS) mean that developing economies are likely to be critical sites of mCDR implementation.

In this study we present a series of perspectives and recommendations derived from a socio-oceanography workshop that considered the requirements for ensuring globally equitable and inclusive mCDR. Particular emphasis is placed on critical considerations for global mCDR governance, including accounting, monitoring and access to technology, knowledge and financial resources. Amongst the key

findings is the urgent need for further dialogue on mCDR governance across countries at different stages of economic development to enhance our understanding of procedural and substantive challenges, and for increased case studies and expert contributions from the global South.

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Soil respiration dynamics in Mediterranean holm oak forest: what does soil respiration tell us about CO_2 flux at the ecosystem scale.

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Soil respiration (Rs) is crucial for understanding the carbon balance in terrestrial ecosystems, particularly amidst climate change, impacting temperature and soil moisture, thus strongly shaping the seasonal Rs trend. In water-limited ecosystems like Mediterranean forests, soil water content plays a pivotal role in driving Rs. However, accurately quantifying its temporal variability through reliable modeling necessitates empirical evidence to parameterize across diverse climatic, edaphic, and forest settings. This study aims to present findings from a two-year case study on CO_2 fluxes in a Mediterranean oak forest, characterized by varying environmental variables. Five plots within the ICOS Level I infrastructure in Castelporziano Estate (Rome, Italy) were examined: four plots had measurement chambers (8200-104 Opaque Chamber, Li-cor) installed on soil sections with undisturbed litter, while one plot had a chamber placed on bare soil to explore the heterotrophic contribution to Rs. Results reveal that Rs was controlled by soil temperature above a threshold value of approximately 10% soil water content, with rain pulses also playing a crucial role, especially during the dry season. Heterotrophic respiration constitutes a consistent percentage of Rs, with levels in undisturbed plots up to 70% higher than in bare soil during the wet season. Integrating Rs with eddy covariance measurements of ecosystem respiration highlights seasonal discrepancies, emphasizing the need for field campaigns to refine modeling and upscaling for more reliable carbon budget estimation.

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Primary productivity signals in the Kolyma River and tributaries in northeastern Siberia

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

Arctic rivers constitute intricate networks where soil carbon is biogeochemically processed before being released into the atmosphere as carbon dioxide (CO_2) or transported to the ocean. As primary producers synthesize biomass from inorganic carbon, the response of these processes in Arctic Rivers to environmental conditions, including climate warming, alterations in hydrology, and shifts in biogeochemistry remains largely understudied. Hydrochemical properties, dissolved O_2 and CO_2 were measured at the surface of the Kolyma River and the tributary Ambolikha during the late freshet (June) and base-flow conditions (August) in 2019. Also, dissolved oxygen-to-argon (O_2/Ar) ratios and the O_2 triple isotopologue composition were measured to assess net and gross biological productivity.

During June and August, the river system exhibited CO_2 emissions into the atmosphere, being the emissions higher at the Ambolikha tributary compared to the main Kolyma channel. Our findings indicate that some hydrological river properties significantly influenced in-stream metabolic processes. In June, the main channel experienced increased water flow and turbidity compared to August, resulting in high CO_2 emissions and low productivity. In August, reduced water flow and greater light penetration facilitated an increase in biological productivity despite lower water temperatures than in June. This was exemplified by a phytoplankton bloom at the confluence of the Ambolikha tributary and the main channel. With the slowing of water flow during extended open-water periods due to climate change, certain regions in Arctic rivers may experience enhanced biological productivity, impacting the carbon budgets of these water bodies.

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CO_2 exchange in a nutrient-rich peatland forest after the application of two distinct harvesting techniques

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

Wide-spread harvesting of peatland forests is foreseen to occur in Finland in the near future. The question is whether continuous cover forestry utilizing partial cuttings could mitigate carbon dioxide (CO_2) emissions and the consequent climatic impact compared to traditional clear-cutting and even-aged forest management.

To assess the impact of clear-cutting vs. partial cutting, we first measured CO_2 exchange with the eddy covariance method for six years in a mature, nutrient-rich peatland forest in southern Finland. Part of the forest was then partially cut (70% of the basal area), and part was clear-cut. The CO_2 exchange of both harvested areas was measured for 8 years. Tree growth was recorded before and after the cuttings to separate the contributions of tree stand and forest floor to CO_2 exchange.

Before the cuttings, the annual CO_2 exchange was about zero, but both cutting methods turned it into a CO_2 source. The partially-cut area became a CO_2 source for the first three years but turned into a CO_2 sink after that, while the clear-cut area was a large, although diminishing, CO_2 source for the whole measurement period. The forest floor was losing carbon both before and after the cuttings. In conclusion, partial cutting resulted in smaller CO_2 emissions than clear-cutting in the short term. However, because trees form only temporary carbon storage in commercial peatland forests, maintaining peat carbon storage is the key to mitigating climatic impact in the long term, which cannot be tackled by changing only the cutting method.

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Methodological evaluation: automatic chamber systems, trade-offs, and refinement of terrestrial CH_4 and CO_2 flux measurements

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Automatic chambers systems (ACS) become increasingly deployed as method for greenhouse gas (GHG) measurements in terrestrial ecosystems. Many different types and differently produced (custom-built or commercial) designs and methodological setups are used in GHG research. Acquired knowledge and advancing insight have made these ACS evolve over years. Variety and some flexibility within ACS designs remains necessary, as different ecosystems require different chamber designs. However, there is no up-to-date consensus on general design, nor is there consensus about dealing with artefacts of chamber deployment that challenge representative measurements, such as the greenhouse effect that heats chamber headspace, vegetation and soil and alters chamber humidity and vapor pressure deficit (I), chamber head space turbulence (II) and non-representative changes in chamber headspace pressure (III).

Our research aims to provide insights in the challenges inherent to the ACS method on the terrestrial trade-offs between CH_4 and CO_2. We present results from literature review, methodological experiments, correlations between environmental parameters and multi-year flux records in peatlands. These insights contribute to better understanding of the ACS method, consensus and to more accurate data within the scientific community and ICOS platforms.

426

Demonstrating the optimisation of cosmopolitan sampling using Copernicus hindcasts

John Allen, Calum Fitzgerald

MyOcean Resources Ltd, Reading, United Kingdom

Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

Within the GEORGE programme (EU Horizon 2020 project 101094716) MyOCEAN Resources Ltd. is helping to support improved integrated multi-RI information and data value chain through deployment of its FleetBot objective optimisation algorithms and procedures. FleetBot was a development of Operational Oceanography, where optimal observational capability was required within available, often minimal, resources and time. Forecast modelling, combined with Near-Real Time data constraint and assimilation is central to the FleetBot processes and drives adaptive sampling, data processing and management strategies. Under GEORGE, cosmopolitan sampling will not be limited to multiple platform types, it will also extend to Research Infrastructures (RIs) flexible sampling programmes and regional ranges; to provide optimised network capacity and programme modification (within permissible ranges/parameters) for sea trials with novel instruments for observation of components of marine carbon pathways.

We will show how FleetBot uses objective optimisation algorithms in predictive environmental model simulations, with cost functions respectful to:

- cosmopolitan observing capabilities,
- the ‘job’ to be achieved, and
- real world requirements and constraints.

We use Copernicus hindcasts to demonstrate the FleetBot processes, in a deep sea region around the Porcupine Abyssal Plain (PAP) site, at both 1/4 and 1/12 degree resolutions. Advising and informing research programmes of their optimal potential and how to attain it, FleetBot monitors ‘past’ ability/skill to predict and correct future sampling/observing. Under GEORGE, FleetBot expands its use of genetic algorithm approaches to advise and inform research infrastructures of their optimal co-operative potential.

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ECOPIA^{TM}, an example for a deep ocean mCDR MRV

Calum Fitzgerald, John Allen, Lonnie Franks

MyOcean Resources Ltd, Reading, United Kingdom

Theme

8. Enhancing the ocean carbon sink: the science, verification, and governance of marine-based carbon dioxide removal (mCDR)

Abstract Text

ECOPIA^{TM} provides a Nature Based Carbon Cycle Management Solution (NBCCMS) effecting an increase in natural capture and storage of carbon through Tele-Illumination of the deep ocean, enabling control and regulation of CO_2 levels in the atmosphere via natural mechanisms. A rigorous, scientific and repeatable Monitoring, Reporting and Verification (MRV) protocol, that is agreed by both the provider (ECOPIA Marine Ltd.) and customers, supported by ocean science and technology, is required to ensure that mCDR (marine Carbon Dioxide Removal) is appropriately measured, quantified, monitored and audited. Importantly the CDR must be verified by independent 3rd parties, and open to further scientific research, to ensure compliance with this MRV protocol.

There are 5 things that CDR should strive to demonstrate:

1. Additionality
2. Avoidance of overestimation
3. Permanence
4. Exclusive claim to Greenhouse Gas (GHG) reduction
5. No association with significant social or environmental harms

We will present how ECOPIA^{TM} has set out this demonstration in it's own working MRV and why we believe it is an example for deep ocean mCDR. Specifically we will show how the planned location provides additionality, how frequent and regular model integration/assimilation of novel monitoring observations constrains overestimation, how global coupled biogeochemical modelling predicts and quantifies permanence, how comprehensive monitoring, alongside location vertically, prevents double issuance and provides exclusivity, and how through simply providing light, and nothing more, there is neither mechanism for preferential pressure on naturally determined biodiversity nor external chemical pressure on the solute composition of the seawater itself.

428

Predicting nitrous oxide emissions from a grain sorghum field using machine learning algorithms

Ifekristi Ogunwobi

University of Florida, Gainesville, USA

Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

Nitrous oxide (N_2O) is a potent greenhouse gas that contributes to global warming and ozone depletion. However, N_2O emissions are often underreported compared to other greenhouse gases. To better understand the drivers of N_2O emissions and find ways to reduce them, we conducted an experiment in the Oklahoma panhandle, United States, in 2021. The study focused on measuring N_2O emissions from a sorghum field using an aerodyne TILDAS flux chamber set up in the middle of the field alongside a flux tower that measures carbon dioxide and water vapor. We collected data on N_2O emission flux every 30 minutes during the production period and used this data to train some machine learning algorithms that could predict daily flux based on several input variables. Having established that rainfall, temperature, soil water, soil temperature, atmospheric temperature, and relative humidity were the major drivers of N_2O emissions from literature, we trained some algorithms using nitrous oxide measured as the target and meteorological data collected from three different sources: Biomet (collected on the field), MESONET (located 100m away from the field), and ERA5-Land (a global atmospheric model). The machine learning model was able to explain 60–78% of the daily flux using these variables. We found that Biomet provided the best estimation value for N_2O emissions. Among all the variables, soil water was found to be the most important in predicting N_2O emissions. This suggests that managing soil water content could be an effective strategy for reducing N_2O emissions from agriculture.

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Assessing CO2 emission sources from a top-down approach based on tracers and carbon isotopes in the Aix-Marseille metropolis area to assess independently the local emissions inventory.

Irène Xueref-Remy[1], Ludovic Lelandais[1,2], Aurélie Riandet[1], Pierre-Eric Blanc[3], Sonia Oppo[2], Sanne Palstra[4], Marvin Dufresne[5], Thérèse Salameh[5], Stéphane Sauvage[5], Alexandre Armengaud[2], Bert Scheeren[4], Huilin Chen[4]

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

The Aix-Marseille-Provence (AMP) metropolis is located in the south-east of France under a Mediterranean climate. This area is known as a hot-spot regarding climate change. AMP is the second most populated urbanized area of France and is estimated to account for ~8% of national fossil fuel CO2 emissions. Its west part is strongly industrialized. AMP aims at reaching carbon neutrality in 2050 and the city of Marseille which is part of AMP is targeting carbon neutrality in 2030.

The air quality monitoring agency ATMOSUD delivers a regional high resolved CO2 emissions inventory that represents the reference for local stakeholders to define emissions mitigation trajectories. However, this inventory requires independent assessments. Within the ANR COoL-AMmetropolis project (2019-2025) we set-up a local CO2 monitoring network based on Cavity Ring Down spectrometers, meteorological sensors and Lidars for monitoring the atmospheric boundary layer height. This local network partly relies on the OHP and ERSA ICOS-Atmosphere stations and on the Fontblanche ICOS-Ecosystem station.

Local meteorological features such as sea and land breezes, and boundary layer dynamics, are shown to strongly modulate local CO2 concentrations. The isotopic analysis of 14C and 13C in CO2 together with a study of CO2 correlations with NOx, CO, black carbon and SO2, show a major impact of fossil fuel emissions on the CO2 urban plumes (mostly traffic and heating and cooking activities) but not as much as the inventory. On the contrary, modern sources such as wood burning seems to account much more than assessed by the local inventory.

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Testing and Deploying Low Cost CO2 Sensors through Citizen Scientists: Results and Findings

pascal joly, Keenan Johnson

Ribbit Network, Seattle, USA

Theme

3. Cross-domain technological development: autonomous vehicles, sensor miniaturisation, low-cost sensors and labour-intense approaches

Abstract Text

Ribbit Network is a non-profit organization with a vision to deploy a global network of low-cost CO2 sensors that can be used by communities for climate science education and to advance our understanding of climate change.

Ribbit Network takes a modular, open-source approach to sensor development. As such, the sensor can be extended and improved over time by the community, with a minimum amount of funding. As more sensors are being deployed, additional use cases are uncovered.

Deploying large-scale networks of low-cost sensors is challenging: finding suitable sites, funding, and citizen scientists willing to deploy and maintain their sensors over time.

Ribbit Network's novel approach is centered on deploying sensors and generating funding with an educational focus.

We showcase 2 engagements Ribbit Network has had over the last year with schools and universities:

- Rutgers University Summer program
- North Carolina School deployment

These engagements have allowed us to fund several projects with leading CO2 ground sensor programs in the Europe and the US:

- Zurich (Dübendorf-Empa monitoring site) - ICOS collaboration - Deployment of 3 frog sensors in an urban environment, and data analysis to evaluate accuracy of the NRID CO2 sensor using a reference high precision sensor co-located at this site.
- Wind River field deployment (Washington State, USA)- Ameriflux collaboration, field deployment in a forested setting.

We will also present the results of several Citizen scientists experiments:

- Testing of Sensirion NRID CO2 sensor accuracy in a controlled environment
- Solar panel-powered sensor

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Analysis of the concentration of methane and carbon dioxide in an area of environmental preservation between the cities of Cananéia - Iguape, southern coast of the State of São Paulo

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Theme

7. Carbon Cycling along the Land Ocean Aquatic Continuum

Abstract Text

The escalation of levels of carbon dioxide and methane (greenhouse gasses) in the atmosphere of these gas species may have several implications for the environment. Regarding coastal systems, increased greenhouse gas emissions can impact the environment through multiple pathways, as the atmosphere and surface ocean waters also have significant exchanges. Studies have indicated that estuaries are essential habitats for a variety of marine life and other species and play crucial roles in their reproduction and the nutrient cycle. Changes in these environments due to increased concentrations of greenhouse gasses may cause changes in the productivity of aquatic plants, the dynamics of organism populations and the chemical properties of water, thus influencing carbon cycles in these ecosystems. The main purpose of this work is to study Greenhouse gasses (GHG), such as CO_2 and CH_4 on the superficial waters of the coastal region of São Paulo. The data were collected in situ on a vessel provided by the Institute of Oceanography of São Paulo University (IOUSP). The campaign was conducted in 2021 (23-25 November) in the south coast of São Paulo state, traveling through cities with low anthropic impacts, which is located in part of Lagamar Complex. For these in situ measurements a portable gas analyzer Microportable Greenhouse Gas Analyzers (LGR-ICOS ™ GLA Series) - was used to detect the CO_2 and CH4 spectra through the Off-Axis Integrated Cavity Output Spectroscopy (OA-ICOS) technique.

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Advancing the Visibility and Impacts of ACTRIS: A Path to Long-Term Sustainability

Giulia Saponaro

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Theme

15. Science communication and outreach to increase the impact of climate research

Abstract Text

ACTRIS is a Pan-European research infrastructure dedicated to atmospheric observations. ACTRIS has recently transitioned from a European Commission project-funded initiative to a recognized European Research Infrastructure Consortium (ERIC), marking a significant milestone in its evolution. This transition formalizes ACTRIS as a legal entity, emphasizing its shift towards operational maturity and sustainability. However, it also highlights the imperative to demonstrate its value and impact to stakeholders for long-term sustainability. This abstract presents the efforts of ACTRIS towards building effective communication beyond scientific realms.

The establishment of ACTRIS ERIC underscores its commitment to transparency, accountability, and stakeholder engagement. The publication of the ACTRIS Business Plan 2023 marks an initial step in this direction, encompassing strategic setup, governance, user strategy, and value creation. The business plan goes beyond financial and governance descriptions, outlining ACTRIS' strategy and cornerstones, emphasizing its commitment to creating value.

Nevertheless, the need for a robust data collection and management system to evaluate ACTRIS impacts over time becomes apparent. This challenge is addressed by considering a framework aiming to capture the multifaceted impacts of ACTRIS, considering its distributed nature and complex organizational structure. By collecting and analyzing longitudinal data, the framework seeks to provide a comprehensive understanding of ACTRIS' contributions to atmospheric research, environmental management, and societal well-being.

Recognizing the importance of value and impact demonstration, it advocates for enhanced transparency, accountability, and stakeholder engagement. Ultimately, effective communication of its values enhances ACTRIS' ability to attract funding, garner support, and foster collaboration for continued advancement in atmospheric research.

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Strong integral carbon cycle constraints from global airborne surveys

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Major investments in GHG measurements from surface networks and satellites have not delivered robust regional to global scale carbon cycle estimates for several reasons: 1) atmospheric transport model biases, 2) surface network sparseness, 3) persistent satellite measurement biases, 4) poor satellite coverage at high latitudes, and 5) poor satellite coverage due to cloud cover elsewhere. Expanded GHG measurements in the atmospheric interior, from aircraft and balloon samplers, are critically needed to connect surface and satellite observations, by evaluating and improving satellite retrievals and atmospheric transport models, and by providing strong integral mass-balance constraints.

To demonstrate this potential, we have compared the posterior concentration output of 48 atmospheric inversions from the OCO-2 v10 MIP experiment to the four global airborne surveys of the NASA ATom project (2016-2018). We find strong flux and concentration dependencies on the observation subset (in situ or satellite land nadir, land glint, or ocean glint) and strong correlations between zonal total (ocean+land) inversion fluxes and tropospheric mass-balance metrics based on column-integrated ATom observations. For example, in the northern extratropics, annual-mean inversion fluxes, which vary by over 2 PgC/yr, correlate strongly with ATom co-sampled concentrations across all models and across observation subsets (r^2 of 0.5 and 0.9, respectively). Emergent constraints based on these correlations can reduce uncertainty on zonal total fluxes by 30-50% relative to the full model suite, on subseasonal to annual time-scales. Tomographic airborne GHG surveys can also provide direct satellite validation and quantitative evaluation of mixing rates in transport models

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Towards accurate quantification of methane emissions from New Zealand's waste and agricultural sources.

Peter Sperlich[1], Christian Stiegler[1], Hinrich Schaefer[1], Gordon Brailsford[1], Rowena Moss[1], Tony Bromley[1], Sally Gray[1], Richard Turner[1], Beata Bukosa[1], Sara Mikaloff-Fletcher[1], Molly Leitch[1], Harrison O'Sullivan-Moffat[1], Amir Pirooz[2], Brendon Smith[3], Michael Kotkamp[4], Alex Geddes[4], Dave Pollard[4], Duncan Holland[4], Dan Smale[4], Richard Querel[4], David Griffith[5], Johannes Laubach[6], Francis Mani[7], Felix Vogel[8], Jocelyn Turnbull[9]

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Theme

1. Isotopes and other tracers for studies of methane sources and sinks

Abstract Text

Increased atmospheric methane (CH_4) mole fractions contribute 0.5°C to the global warming in 2010-2019 relative to 1850-1900. A range of natural and anthropogenic sources contribute to the rise in atmospheric CH_4. The international CH_4 pledge requires countries to urgently take action to reduce CH_4 emissions, including those from agriculture and waste. However, current techniques to calculate and thus manage CH_4 emissions have large uncertainties on the order of 30-100%. This uncertainty is economically significant with the pricing of emissions.

We are currently developing a suite of new techniques to measure CH_4 emissions on small spatial scales, i.e., paddock to facility scale. This includes in situ CH_4 analysers deployed on airborne, ground-based mobile and ground-based stationary observation platforms. We determine CH_4 emission fluxes from measured CH_4 mole fractions using a range of techniques, including tracer:tracer, mass-balance, and an inverse approach coupled to a high-resolution computational fluid dynamics model. We present our new methods and will show first results from a controlled-release experiment, which measures the accuracy and the resolution of our techniques.

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Climate Fresk makes climate change related information accessible to everyone

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Theme

16. Continuous Learning in a changing world - Teaching and learning novel tools & methods used for measurement techniques', data & policy

Abstract Text

Climate Fresk is a 3-hour workshop about climate change. It is a scientific, collaborative, and engaging way to raise awareness about climate change to anyone over 15 years. The workshop is based on the IPCC reports breaking down the key mechanisms behind climate change. In just three hours, the workshop will help you understand the fundamental science behind it and empower you to act.

The concept consists of a deck of info cards laid on a table or online on a white board solution. There is no lecture involved, but the participants use their collective intelligence to solve the cause-and-effect connections between the cards.

Climate change is a difficult topic, and it often brings stress to people. A crucial part of the session is to make the participants discuss solutions. The facilitator gathers the ideas and leads a discussion with the group. In the end the participant has learned about climate change, had a good time working together with the group, and a desire to act for a better future.

Climate Fresk NGO was founded in 2018 by Cédric Ringenbach, who also invented the Climate Fresk workshop. By 2024 it has had over 1,6 million participants. Climate Fresk NGO trains facilitators that lead the workshops.

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Quantifying CO_2 Emissions from Large Point Sources in the Indian Region: A Data-Driven Approach using Satellite Measurements.

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

The reliability of carbon emission estimates over India via atmospheric inverse modelling approaches suffers from the paucity of atmospheric carbon observations. Recent advancements in satellite-based remote sensing technologies, such as OCO3 and other upcoming satellites (eg, CO2M) with specialized sensors for high-resolution greenhouse gas monitoring, offer promising avenues. The emissions landscape within India is characterized by the dominance of localized point sources, notably thermal power plants, and urban centers, necessitating precise emission quantification from these focal points. Our study endeavours to exploit targeted observations from OCO3 and forthcoming satellites to quantitatively characterize carbon emissions from these emission hotspots across India. Instead of computationally demanding atmospheric inverse modelling paradigms, our methodology relies on a data-driven framework for emission inference with the aid of a recently released Python library, Data-Driven Emission Quantification (ddeq) (Kuhlmann et al, 2024). This study is designed to critically assess the efficacy and reliability of satellite-based data-driven methodologies for carbon emission estimation over the Indian region and will be carried out with close collaboration with the ddeq package developers at Empa, Switzerland. The outcome of this research will provide valuable insights for informed climate policy formulation and mitigation strategies tailored to the nuances of the Indian emissions landscape.

Reference

Kuhlmann, G., Koene, E. F. M., Meier, S., Santaren, D., Broquet, G., Chevallier, F., Hakkarainen, J., Nurmela, J., Amarós, L., Tamminen, J., and Brunner, D., : (2024). The ddeq python library for point source quantification from remote sensing images (version 1.0). EGUsphere, 2024, 1–27. Retrieved from https://egusphere.copernicus.org/preprints/2024/egusphere-2023-2936/ doi: 10663.5194/egusphere-2023-2936

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High-resolution modeling of CO_2 in the Netherlands and the dispersion of emissions from the Randstad using DALES

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Efforts to develop effective global climate mitigation strategies require high-resolution weather and climate forecasts. The Dutch Ruisdael Observatory is a key initiative aimed at providing such forecasts for the Netherlands. In frame of this infrastructure project, we extended the Dutch Large-Eddy Simulation (DALES) model with the capability to simulate the dispersion of CO_2 emissions and plume rise in the turbulent boundary layer. DALES can explicitly model large turbulent flow features, allowing highly detailed simulation (~100m) that makes it well-suited for the objectives of the Ruisdael Observatory project. Here, we present initial results from a simulation at 150x150m^2 resolution, covering the main urban area of the Netherlands (51.5 - 52.6°N, 3.25 - 6.25°E). To provide a realistic simulation of the CO_2 variability that is measured by the Ruisdael Observatory, the model uses meteorological forcing from the HARMONIE-AROME weather forecasting model, background CO_2 concentrations from CAMS, point source emissions from the national emission registry, along with downscaled emission inventories derived from 1x1km^2 area emission data (available at www.emissieregistratie.nl). The procedure is conducted using sector specific downscaling workflows for the main emission categories. Besides anthropogenic emissions, we included biogenic CO_2 components from vegetation, which are interactively simulated using the heterogeneous land-surface model of DALES. Validation against in-situ Cabauw tower measurements obtained in frame of the ICOS project (https://data.icos-cp.eu/portal/) demonstrates a good performance of the model, affirming that DALES is an appropriate tool for investigating the urban-scale CO_2 emission distribution and plume evolution in turbulent environments. These results provide valuable insights into emission transport and dispersion, needed for the use of atmospheric measurements to reduce the uncertainty in emission modeling and to contribute to the development of effective climate policies.

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Sensing the Forest: how can artistic and scientific methods be combined to inform and educate people about climate change?

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Theme

15. Science communication and outreach to increase the impact of climate research

Abstract Text

The EC flux tower run by Forest Research in Alice Holt (UK) is only 5 km away from a 250 ha forest visitor centre that attracts over 350,000 visitors per year. We regularly host visits for small special interest groups and university courses at the tower, but finding ways to engage the public with our work can be more of a challenge.

Sensing the Forest (sensingtheforest.github.io) is a project funded by the UKRI Arts and Humanities Research Council that aims to raise awareness among forest visitors, artists, scientists, and the general public about the connection between forests and climate change. Community building centres on looking at a better understanding of forest behaviour using complex scientific data in creative and artistic ways.

As part of this project, Forest Research scientists are involved in providing data from our EC flux tower (real-time and historical) that can be used by artists to make temporary sound installations in the forest.

Here, we will share some of the exciting outputs from the project, as well as reflections on how collaborations across disciplines can help engage new audiences with our science.

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Inorganic carbon system in the Northwest European Shelf: A new consistent data product

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

While representing only~7% of the global ocean area, continental shelves play an important role in the marine carbon cycle. Consistent and quality-controlled data products such as GLODAP are useful to assess the inorganic carbon system evolution in space and time. However, GLODAP focuses on the open ocean, limiting our understanding of the inorganic carbon system in shelf seas. Because of its high heterogeneity and expected capacity to export and bury carbon, the Northwest European Shelf (NWES) is of interest among coastal shelves. To help understand the inorganic carbon system in this region, we present a consistent data product including inorganic carbon parameters (total alkalinity, dissolved inorganic carbon, pH) as well as physical and nutrient variables. This product, focusing on the NWES above 1000m and between 43°N and 70°N, aims to gather data from different measurement platforms (cruises, stations, moorings, gliders…) from the surface ocean and water column, to assess the variability of the inorganic carbon system and its evolution with time. Data from estuaries, delta and fjords are also included. We have compiled multiple datasets for a total, so far, of about 45.000 inorganic carbon data points from around 520 cruises or stations. These data have been merged into a unique format and efforts have been put into the quality control in order to ensure the consistency of the entire product with regard to the high spatial, temporal and environmental variability of the NWES as well as the difference in uncertainty and resolution between the different platforms.

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Exploring ground-based observations at Xianghe, China: A WRF-Chem study of CO_2, CH_4 and CO variability

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Theme

10. Remote sensing of greenhouse gases from ground and space: Their application for carbon cycle studies, satellite and model validation and building MVS capacity

Abstract Text

This study analyses the temporal variability of CO_2, CH_4, and CO concentrations at the Xianghe site in China using the Weather Research and Forecast model coupled with Chemistry (WRF-Chem). HIgh-resolution model simulations are compared with in situ (PICARRO) and remote sensing (TCCON-affiliated) measurements from September 2018 to September 2019. The analysis reveals good agreement between observations and simulations, while contributions from various anthropogenic sectors and the biosphere to the concentrations are revealed based on tracked tracers. Meteorological factors, particularly wind direction, strongly influence the measurements at the site, with southwest winds transporting polluted air from the North China Plain. Discrepancies in CH_4 simulations are attributed to biases in emission inventories and boundary conditions. This study highlights the value of WRF-GHG to interpret both surface and column observations at Xianghe, offering source sector attribution and insights in the link with local and large-scale winds based on the simultaneously computed meteorological fields. However, given the long lifetime of the considered species and the fact that WRF-GHG is a regional model, accurate initial and lateral boundary conditions remain crucial. The dependence on precise input emission data on the other hand, can be used to evaluate the existing bottom-up inventories.

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Estimation of daily CO2 fluxes using a statistical approach based on multi-satellite optical images and meteorological data

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Estimating greenhouse gases emitted or stored by agricultural land is a challenge, particularly with a view to quantifying the climate change mitigation potential of soil carbon storage. In this context, this study aims to estimate daily CO_2 fluxes (i.e., NEE, GPP and RECO) using a statistical approach based on multi-temporal satellite images and meteorological data.

The proposed approach is based first and foremost on the CROP 2021 initiative (which aims to collect standardized fluxes and meteorological data from European flux database) and the availability of satellite images following the recent launch of the Sentinel-2A/B satellites. Different study cases are tested, with implementation of the approach by study site (R^2 on NEE ranging from 0.58 to 0.90), or establishment of a global statistical model on all the available crop/site years (R^2 of 0.75 on NEE).

At two pilot sites located in south-western France (with regular optical satellite acquisitions since 2006, delivered by eight satellites, namely Formosat-2, Spot-2/4/5, Landsat-5/8 and Sentinel-2A/B), the approach is being tested on a database with greater temporal depth. As an example, on the Auradé site, where wheat, sunflower, rapeseed, and barley are grown (and intermediate cover crops in recent years), the approach has R^2 values greater than 0.80.

The proposed approach can be applied in various contexts, including: gap filling, prediction of fluxes data, or calculation of carbon budget (using cumulative NEE or NEP) associated with information on agricultural practices (e.g., data on organic amendments, managements of crop straw and exported yield).

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Inverse modelling of anthropogenic and natural CH_4 emissions over Europe

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Methane (CH_4) is the second most important anthropogenic greenhouse gas (GHG) after carbon dioxide (CO_2), with molar ratios more than doubled since pre-industrial times. Most important anthropogenic and natural sources of CH_4, are from coal, oil and gas mining, waste processing, livestock, and natural wetlands. Anthropogenic emissions are estimated using “bottom-up” inventories, whereas natural emissions are derived from land surface modelling. However, these processes (and therefore emissions) have large uncertainties. To obtain more accurate emission estimates, inverse modelling techniques are developed that make use of atmospheric measurements.

This study applies the CH_4 inter-comparison protocol, as established with support of World Meteorological Organization - (WMO-IG^{3}IS) and the Copernicus CO_2 ($CoCO_2$) project. The objective is to assess the constrains of atmospheric CH_4 measurements, obtained from Integrated non-CO_2 Greenhouse gas Observing System (InGOS) project and Integrated Carbon Observation System (ICOS) and other networks, on national CH_4 fluxes over Europe for different years, and investigate the uncertainties and trends in anthropogenic and natural CH_4 fluxes following a set of experiments, as defined in the protocol.

The state of art Weather Research and Forecasting with GHG (WRF-GHG) transport model, coupled to CarbonTracker Data Assimilation Shell (CTDAS) participates in this intercomparison. CTDAS uses the Ensemble Kalman Filter, with 150 ensemble members, to estimate posterior CH_4 emissions for different European countries. For this study, CTDAS optimises anthropogenic and natural prior fluxes, with the aim to understand how well the observational network constrains the emissions. The use of isotopes and satellite data could be used to further improve the results.

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Shoulder season controls on methane emissions from a boreal peatland

Katharina Jentzsch[1,2], Elisa Männistö[3], Maija E. Marushchak[4,5], Aino Korrensalo[5,6], Lona van Delden[1], Eeva-Stiina Tuittila[3], Claire C. Treat[1]

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Cold-season emissions substantially contribute to the annual methane budget of northern wetlands, yet they remain underestimated by process-based models. Models show significant uncertainty in their parameterization of processes, particularly during the transitional phases of freezing and thawing temperatures in the shoulder seasons. Our aim was to identify the environmental controls on the components of the methane fluxes - methane production, oxidation, and transport - from a boreal peatland during the shoulder seasons. We partitioned net methane emissions into their components by combining manual chamber flux measurements on vegetation removal treatments with pore water sampling for concentrations and stable carbon isotope ratios of dissolved methane at Siikaneva bog in Southern Finland between May and October 2022. The results suggest that several processes dampen the decrease in shoulder season emissions related to decreasing methane production rates with decreasing temperatures. Firstly, highly efficient transport of methane through the aerenchyma of peatland sedges continued outside of the growing season after plant senescence. Secondly, decaying vascular plants provided additional substrate for methane production at the end of the growing season. Thirdly, accumulation of methane in the pore water partly delayed the emission of methane produced in summer and winter to the shoulder seasons. Substrate limited oxidation rates, however, largely compensated for the higher diffusion rates related to high pore water concentrations in fall. Accounting for these processes specific to the shoulder seasons by separately modelling the components of methane fluxes will likely work against the underestimation of cold-season methane emissions from northern peatlands.

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Source attribution of pasture-scale N_2O fluxes using a random forest approach

Christof Ammann, Lena Barczyk

Agroscope, Zürich, Switzerland

Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Grazed and fertilized pastures are considerable sources of the greenhouse gas N_2O. While fertilizer applications usually lead to short emission pulses, animal excreta lead to small-scaled emission hotspots resulting in a strong spatial and temporal source variability that represents an inherent problem for the quantification of gaseous emissions from pastures with chamber techniques. The eddy covariance method, integrating emissions over a larger footprint domain, is well suited to quantify total field-scale N_2O emissions, but the attribution to sources and the determination of emission factors is still a challenge.

We present results of a 3-year field experiment carried out in Switzerland. The investigated pasture was grazed by dairy cows in an intensive rotational management and additionally received organic and mineral fertilizer. Field-scale N_2O fluxes were quantified with the EC technique. The management and environmental conditions resulted in high temporal and spatial dynamics of the N_2O fluxes with highest values typically occurring after fertilization events in the summer months. Total annual N_2O emissions amounted to between 3 and 5.5 kg N ha^{-1} y^{-1}.

A random forest based gap filling and partitioning method was used to attribute the observed field-scale emissions to the main source classes (grazing excreta, fertilizer application, and background) and to derive an average N_2O emission factor for grazing excreta of 1.1±0.5%. Using random forest and other regression methods also the effect of environmental parameters on grazing-related emissions were analyzed. They indicated, that classical chamber based emission factors for animal excreta may underestimate the emission on real pastures.

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Dijon Metropole journey towards carbon neutrality

Denis Hameau

Dijon Metropole, Dijon, France

Theme

12. Translating Scientific CO2 Emission Research into City Services

Abstract Text

As cities worldwide grapple with the urgent imperative of reducing carbon emissions, Dijon Metropole presents a compelling case study in translating scientific CO2 emission research into tangible city services. Committed to becoming an ecological reference point but recognizing the challenges inherent in achieving its ambitious targets, the Metropole has embarked on a journey towards carbon neutrality by 2050, exemplified by its territorial climate and energy plan.

Within this framework, the preservation of biodiversity and conservation of resources are integral components of Dijon's sustainability strategy. In its quest for innovative solutions, the Metropole collaborates closely with research institutions and higher education bodies, recognizing the collective wisdom needed to address complex challenges. Moreover, Dijon underscores the transformative potential of data, not only as a tool for innovation but also as a means to empower citizens and enhance service delivery.

This presentation offers a glimpse into Dijon determined approach to translating scientific CO2 emission research into city services, illustrating the ongoing journey of discovery and adaptation in the pursuit of a sustainable future for all.

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Simultaneous hot and dry extreme-events increase wetland methane emissions: An assessment of compound and discrete extreme-event impacts using Ameriflux and FLUXNET-CH4 site datasets

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

Wetlands are the largest natural source of global atmospheric methane (CH4). Despite advances to our understanding of changes in temperature and precipitation extremes, their impacts on carbon-rich ecosystems such as wetlands, remain significantly understudied. Here, we quantify the impacts of extreme temperature, precipitation, and dry events on wetland CH4 dynamics by investigating the effects of both compound and discrete extreme-events. We use long-term climate data to identify the extreme-events and CH4 fluxes measured across 46 eddy covariance sites, sourced from the FLUXNET-CH4 database and Ameriflux project, to assess impacts on wetland CH4 emissions. These findings reveal that compound hot+dry extreme-events lead to large increases in daily CH4 emissions. However, per event, discrete dry-only extreme-events cause the largest total decrease in CH4 emissions, due to the long duration of events. Despite dry-only extreme-events leading to an overall reduction in CH4 emissions, enhanced fluxes are observed for the first days of dry-only events where, the timing and magnitude of this pattern differed between boreal and temperate biomes. Lagged impacts are significant for at least the 12 months following several types of extreme-events. These findings have implications for understanding how extreme-event impacts may evolve in the context of climate change, where changes in the frequency and intensity of temperature and precipitation extreme-events are already observed. With increasing occurrences of enhanced CH4 fluxes in response to hot-only and hot+wet extreme-events and fewer occurrences of reduced CH4 fluxes during cold-only extreme-events, the impact of wetland CH4 emissions on climate warming may be increasing.

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Simulating in situ ecosystem carbon fluxes in croplands at sub-hour resolution from UAV-based anchoring points and wavelet analysis

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Theme

14. Leveraging Direct Flux Measurements Beyond Academia for Real-World Applications

Abstract Text

The accurate monitoring of ecosystem fluxes of organic carbon (C) in agroecosystems is crucial for greenhouse gas accounting in croplands and allow fair carbon crediting programs. However, the broader implementation of precise C accounting faces limitations due to the scarcity of direct flux measurements. Here, we present a methodological framework for simulating in situ carbon fluxes in agricultural sites (i.e. net ecosystem exchange, NEE), with minimal requirements, which preserve quasi-observational properties. The mean net plant carbon uptake signal can be captured via UAV surveying during the photosynthetic season or via destructive biomass sampling. The soil respiration component is simultaneously measured, or modelled. Together, both components capture the development of the mean NEE. Next, our goal is to warp the mean carbon signal to accurately capture the daily carbon fluctuation pattern characteristic of European cropland ecosystems. From a set of comparable cropland site-years under standardized monitoring (N= 26), we extract the time series features to characterize the seasonal component of the signal. Based on the mean carbon signal and derived bounding thresholds, we define a minimization problem to warp the carbon exchange signal. In such way, we construct a NEE time series that simulates the measured carbon flux characteristics, from yearly to sub-hour time scales. The quality of the method is evaluated on an unseen ecosystem cropland site not involved during modelling. The comparison of initial results reveals a favorable agreement between simulated and measured fluxes, indicating the method's suitability for in situ ecosystem carbon flux assessment in European croplands.

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Investigating Vienna's CO_2 and CH_4 emissions with tall tower eddy covariance flux measurements

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Cities are responsible for the large majority of carbon dioxide (CO_2) emissions from fossil fuel combustion and are furthermore sources of significant methane (CH_4) emissions. Drastic and rapid reductions in urban emissions of these greenhouse gases (GHGs) will therefore be essential in achieving the overarching climate change mitigation goal of the Paris Agreement. Collectively, as well as individually, cities have committed themselves to ambitious net zero emissions targets. Developing and implementing policies/measures to achieve these goals depend on accurate and timely quantification of urban GHG emissions. The Vienna Urban Carbon Laboratory is investigating if, and how, local measurements of atmospheric CO_2 and CH_4 can support emissions monitoring in the Austrian capital. This conference contribution will present and discuss the analysis of turbulent CO_2 and CH_4 fluxes observed with eddy covariance (EC) at 144 m above the city surface. EC fluxes of CO_2 have been observed since December 2017, CH_4 fluxes since May 2022. Local inventories of aggregate, sector emissions of CO_2 and CH_4 were resolved in time and space for comparison with the respective flux measurements. For the inventory-flux comparisons, two standard flux footprint models were used for extracting and weighting the respective gridded emission estimates. The discussion of the results will focus on how the inventory-flux comparisons can inform on verification and/or improvement of the official inventories. Furthermore, gap-filled, yearly CO_2 flux estimates will be presented to discuss the potential use of urban EC as an early indicator of interannual trends in local emissions.

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Land-ocean continuum as ideal spots to study ocean alkalinity enhancement - the case of the southern Baltic Sea.

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Theme

7. Carbon Cycling along the Land Ocean Aquatic Continuum

Abstract Text

Regions being a transition zone between land and ocean are key components in global carbon cycling. They already have been recognized as important hotspots for terrestrial organic matter remineralization and burial. Still, however, little is known about transformations of the carbonate system occurring in the land-ocean continuum. This was a motivation to establish in 2016 a carbon observatory in the Vistula River mouth and the coastal Gulf of Gdansk (southern Baltic Sea) comprising a regular, weekly sampling of inorganic and organic carbon species. The study revealed that alkalinity concentrations are increasing both in the southern Baltic Sea (3.4 µmol kg^{-1} yr^{-1}) and also in the Vistula River water (42 µmol kg^{-1} yr^{-1}). Furthermore, the data indicates that loads of alkalinity from land/river may be regulated seasonally with a net effect of organic matter production and remineralization in the land-ocean continuum. These processes, through extreme changes in pCO_2 (from ca. 100 µatm to >2000 µatm) modify significantly the water pH leading to very high either under- or super-saturation of calcium carbonate and its spontaneous mineral precipitation and/or dissolution. These processes still require quantification, however, seasonal fluctuations in river alkalinity range from approximately 2000 µmol kg^{-1} to as much as 4050 µmol kg^{-1}.

This study shows a need for consistent and holistic observations of inorganic and organic carbon cycling in the land-ocean continuum zones. But it also identifies a natural-based alkalinisation in the southern Baltic Sea, which could be a perfect spot for studying the ocean alkalinity enhancement concept.

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Impact of CO_2 fertilisation on carbon allocation patterns in a sub-Arctic rich fen peatland

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Theme

6. Greenhouse gas fluxes at high latitudes and climate/human induced feedbacks

Abstract Text

The high latitudes have been experiencing unprecedented warming compared to the rest of the planet. The peatlands in this region store a vast amount of carbon (C) which is getting exposed to the climate warming. Although a wide range of studies have assessed peatlands' C cycling, our understanding of the factors governing source–sink dynamics and internal C pool allocation and residence time of peatland C stock under a warming climate remains a critical uncertainty at site, regional, and global scales. Using an intermediate complexity terrestrial ecosystem model; Data Assimilation Linked Ecosystem Carbon (DALEC) model version 2, calibrated by a Bayesian framework (with publicly available datasets for 2014 to 2020), we found that the greening trend in the peatland is forced by a CO_2 fertilisation effect which in combination resulted in increased gross primary production (GPP). Relative to 2014, GPP increased by ~75 gC m^{-2} $year^{-1}$by 2020 (95% confidence interval: –41.35 gC m^{-2} $year^{-1}$ to 213.55 gC m^{-2} $year^{-1}$). Consequently, the fen peatland allocated more photosynthate to foliage (~50%) than the structural (~30%) and fine root C pools (~20%).

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Identifying the interannual variability (IAV) of terrestrial carbon fluxes and their response to climate change from observational perspectives

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Knowledge of the interannual variability (IAV) of global carbon cycles is crucial for evaluating our climate mitigation pathways to achieve the Net Zero. Upscaling eddy covariance (EC) carbon fluxes from tower to regional/global scales with Earth observation, metrology forcing, and machine learning techniques informs climate change studies e.g., terrestrial modelling, from an observational perspective. However, capturing flux IAV faces great challenges from the uncertainty of forcing data and EC towers. Here, we examined factors affecting upscaled carbon fluxes and IAV for global and European ecosystems and identified their responses to climate change with FLUXNET2015 and ICOS Warm Winter databases, and the Uniform FLUXes (UFLUX) framework. The findings suggested that the selection of forcing datasets had large influences on estimated flux magnitudes but little influence on IAV. The intensity of El Niño & La Niña as well as the spatiotemporal distribution of EC towers were pivotal for capturing the flux IAV. Whilst the influence of partitioning methods and gap-filling was inconsiderable. In addition, we found that European land ecosystems kept losing net carbon sequestration by 0.07 Mg C ha^{-1} yr^{-1} between 2000 and 2020. The loss was mainly due to increases in ecosystem respiration as a result of rising air temperature.

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Impact of drought on urban green areas in Southern Finland

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

More than half of the world's population lives in urban areas, and urban settlements contribute around 70% of the global CO2 emissions. Enhancing the carbon sequestration of urban green infrastructure has been identified as an option for mitigating climate change. In addition, urban green areas can also help to manage run-off water, reduce the urban heat island effect, and have further health related co-benefits. Climate change-related risks are increasing, and urban green areas are subjected to stress factors such as heat, pollution, and drought.

We studied carbon cycle components of urban green areas focusing on the impact of drought. The study area is Kumpula, a semi-urban area situated in Helsinki, Southern Finland. We use the JSBACH ecosystem model together with observations from an intensive measurement campaign conducted from 2020 to 2021. The site consists of a park area with lawns and linden trees (Tilia cordata) and an urban forest dominated by birch (Betula pendula). In addition, some parts of the site were irrigated. The field observations included soil texture, soil temperature and moisture, sap flow, photosynthesis, and soil respiration. Remote sensing data (Sentinel-2) was used to follow development of the leaf area index. Furthermore, we used net ecosystem exchange from eddy covariance measurements (2006-2023) at the Kumpula SMEAR III urban measurement station, operated by the University of Helsinki.

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Quantifying the impact of different Carbon Farming practices using Eddy Covariance

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Theme

14. Leveraging Direct Flux Measurements Beyond Academia for Real-World Applications

Abstract Text

Carbon farming is a rapidly growing field with the potential to mitigate climate change by increasing soil carbon sequestration. As carbon accounting becomes a bigger business, accurately quantifying the impact of carbon farming practices becomes crucial for generating reliable carbon credits. However, there is still a great deal of uncertainty about the effectiveness of different practices. Eddy covariance measurements provide a useful tool to quantify the impact of carbon farming on soil carbon sequestration. We have established a unique field experiment with two eddy covariance towers on two adjacent plots of agricultural land. Farming practices on one plot will be business as usual, while on the other plot focused on maximum carbon uptake and minimal water loss. This setup allows us to directly compare the effects of different farming practices on soil carbon and water fluxes towards more sustainable agriculture. The field sites are located in Westmalle, Belgium; the setup was installed late 2023. Currently we are assessing the starting conditions at both plots. We will present the research objectives and some preliminary results from the experiment.

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Advance Marine Research Infrastructure Together. A federated services project for ocean observing and data products

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Theme

17. Best Practices in the landscape of Research Infrastructures: Cooperation, Co-location and other lessons learned

Abstract Text

Understanding the ocean's role in the carbon cycle is a major focus of scientific research and of Ocean Observing Systems (OOS) as the ocean is the main sink for anthropogenic carbon. Processes need to be better understood, and spatial variability of the source/sink better quantified, so that budget can be correctly computed.

The Global OOS needs to evolve to better address these issues, with European organizations making a greater contribution to carbon measurement.

In situ carbon measurement technology has developed in recent years, and the containerization of sensors and their miniaturization have enabled them to be integrated on a growing number of platforms: ships, moorings, profiling floats and autonomous vehicles.

AMRIT, a Horizon Europe project which started in 2024, brings together ocean observation Marine Research Infrastructures and key organizations to homogenize the metadata from the sensors to the end users, and to provide integrated and open services to improve the overall data value chain. This will enhance the quality of products such as climate atlases, particularly for carbon, and ensure that they meet the needs of all users. AMRIT will develop its federated services within the framework of the European OOS, currently under development.

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Interannual and seasonal variability of the air—sea CO_2 exchange at Utö in the Baltic Sea

Martti Honkanen[1], Mika Aurela[1], Juha Hatakka[1], Lumi Haraguchi[2], Sami Kielosto[2], Timo Mäkelä[1], Jukka Seppälä[2], Simo-Matti Siiriä[1], Ken Stenbäck[1], Juha-Pekka Tuovinen[1], Pasi Ylöstalo[2], Lauri Laakso[1,3]

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Theme

7. Carbon Cycling along the Land Ocean Aquatic Continuum

Abstract Text

Coastal seas host intense carbon cycling, as they are active regions transporting and transforming organic matter. High frequency measurements are required to understand the temporal variability of the air—sea exchange of carbon dioxide (CO_2) in these biogeochemically dynamic regions. We measured the air—sea fluxes of CO_2 at Utö Atmospheric and Marine Research Station, located in the Archipelago Sea in the Baltic Sea, during 2017—2021. The flux measurement was based on the eddy covariance technique, supported by the flux parametrization based on CO_2 partial pressure (pCO_2) and wind speed. Auxiliary physical and biogeochemical data collected were vital for understanding the drivers of the temporal variability of the fluxes. The phytoplankton blooms caused the sea to act as a sink of CO_2 in spring—summer. The remineralization of the organic matter, enhanced by the breakdown of the water column stratification, started to dominate over the carbon fixation in autumn, turning the sea to a CO_2 source for the autumn—winter. On the annual basis, the sea close to Utö station was a net source of CO_2, which indicates that advected carbon was entering the system, possibly originating from the terrestrial ecosystems. In 2017—2021, the highest annual net air-sea exchange of CO_2 was twice as high as the lowest one. The carbon cycle in these two years (highest and lowest) differed greatly in terms of the sea surface pCO_2 drawdown in spring—summer, which was affected by the intensity of the algal blooms and physical properties of the mixed layer.

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Inverse transport and dispersion modelling for the Oslo area for urban greenhouse gas emissions assessment

Ignacio Pisso, Susana Lopez Aparicio, Dam Thanh Vo, Franck Dealuge, Terje Krognes

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Norway has set the target of cutting greenhouse gas (GHG) emissions by at least 40% compared to 1990 levels by 2030. This goal will require the implementation of policy measures aiming at strong reductions of GHGs emissions, especially in the urban environment. This work assesses a GHG emission flux methodology including uncertainty estimates based on inverse transport modelling and optimized use of measurements, in order to inform a local GHG urban emission inventory. Two urban CO2 emission inventories for Oslo were produced. Development of small sensors based on off-the-shelf open components and open source software yielded an operational prototypes, together with the assessment of associated uncertainties. In addition, alternative models for data storage and distribution have been explored (distributed databases). We studied potential future applications to networks of autonomous small sensors and the problem of optimal measurement locations based on transport modelling produced with an updated version of the LPDM FLEXPART. We present updates on the work on optimization of emission estimates and their uncertainties based on inverse modelling (optimization based on source-receptor relationships). Sensitivity studies of the relationship of spatio-temporal scales of input and output of the dispersion model were run. In addition to the observation system simulation experiment, we present experimental measurements and discuss the implications for the data exchange formats, the algorithms and data structures that could be used for inter-comparisons with similar activities in other urban areas. In addition, the use of complementary non-CO2 atmospheric compounds (CO and APO) and 14CO2 is introduced.

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Inverse modeling of emissions of CH4, N2O and F-gases in Europe: an intercomparison study of three inverse methods

Daniela Brito Melo[1], Alice Ramsden[2], Helene De Longueville[3], Alison Redington[2], Alexandre Danjou[3], Peter Andrews[2], Brendan Murphy[3], Joseph Pitt[3], Eric Saboya[4], Matthew Rigby[3], Lukas Emmenegger[1], Alistair Manning[2], Stephan Henne[1], Anita Ganesan[4]

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

National emissions of greenhouse gases (GHG) can be quantified using regional atmospheric inverse modelling. This technique combines observations of GHG concentrations with source sensitivities derived from an atmospheric transport model (ATM) to determine an estimate of GHG emissions that best-fits the observations (top-down method). Whilst inverse modelling is an independent approach to estimate the emissions of GHGs at the country/regional scale, in Europe, this technique is currently only used by the United Kingdom and Switzerland as supportive information when reporting their GHG emissions to the UNFCCC.

Within the Horizon Europe research project Process Attribution of Regional emISsions (PARIS), we have estimated emissions of CH4, N2O and fluorinated gases from 8 European countries between 2018 and 2023 using different combinations of three inverse models and two Lagrangian ATMs. The sensitivity of the results to the inversion framework, to the selected ATM, and to various assumptions was studied. We examined the effect of background concentrations specification, choice of a priori emissions, and filtering of observations on the top-down emission estimates. Aligning these factors largely improves the agreement of a posteriori emissions obtained from the different inverse models, indicating the robustness of the different inversion approaches.

This intercomparison study leads to an improved quantification of the uncertainty of top-down emissions, which is generally higher than the a posteriori uncertainty obtained from any individual inverse model. By working with national inventory teams, the estimates of inverse models can improve the reporting of national GHG emissions and help countries review their national mitigation strategies.

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Impact pathways – towards demonstrating the socio-economic impact of RIs

Evi-Carita Riikonen, Werner Kutsch

ICOS ERIC, Helsinki, Finland

Theme

17. Best Practices in the landscape of Research Infrastructures: Cooperation, Co-location and other lessons learned

Abstract Text

The key component of the value chain that determines an RI's societal significance is establishing the link between an RI's operations and the economic and social decision-making that results from them, subsequently having a long-lasting impact on society. However, demonstrating or communicating the often slowly evolving impact that especially the environmental RIs generate is challenging. The materialisation of impacts is not only stretched over long time periods, but is also diverse and develops through a complex set of channels and phenomena.

In this presentation, we explore the concept of “impact pathway” and discuss how it can be a useful approach to identify the chain of events and multiple factors that contribute to the materialisation of RIs’ societal impact. We argue that to demonstrate the potential societal impacts, it is crucial to recognise and narrate the whole process within which impact is generated, starting from linking together the RI’s performance and expected impacts.

As an example, we delve into the ‘publications-citations-recognition’ pathway, which, simply put, means a ‘knowledge push’ where the RI generates scientific publications either directly or via its users, and the publications produce citations by other users and eventually form a new body of knowledge. Later on, the body of knowledge is recognised within a broader research community and society. Eventually, the RI-generated knowledge may be applied to societal problem-solving efforts or translated into economic benefits.

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Unifying drought research across ICOS sites through Standardized Hydrometerological Indices: Theory and application

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

The critical role of ecosystems in the global carbon cycle, combined with the increasing frequency of extreme hydroclimatic events, highlights the need for comprehensive tools to study these phenomena. ICOS sites provide unique insights into ecosystem responses to extreme events, but distinguishing between normal and extreme climatic conditions is a difficult task that requires centuries of observations and a robust framework. In practice, a wide range of definitions, or none at all, are used for extreme conditions, making comparisons between studies virtually impossible.

Here, we present a novel dataset of daily hydrometeorological indices for defining extreme climatic conditions. We combine an already established method for standardised indices with high temporal data, empirical statistics and soil moisture simulations to provide a flexible and comprehensive dataset for describing hydro-climatic conditions at ICOS sites. In total, we calculated the Standardised Precipitation Index (SPI), the Standardised Precipitation Evapotranspiration Index (SPEI) and the Standardised Soil Moisture Index (SSMI) for 101 ICOS ecosystem sites from 1950 to 2021. Additionally, we included simulated soil moisture and evapotranspiration from the Mesoscale Hydrological Model (mHM).

This standardised approach allows study results to be compared across different ecosystem and climate types. It is intended to complement indices already in use and will help to synergize studies across ICOS sites. We present ideas on how to incorporate them into drought research, and all researchers are invited to review the data for their sites and discuss further development to collectively build a strong foundation for drought research across ICOS sites.

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Two years measurements of carbon dioxide, energy and water vapor fluxes above a young oil palm plantation (*Elaeis guineensis Jacq.*) established in southeast Benin, West Africa

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Theme

13. In situ data for climate and other environmental services and policy support

Abstract Text

In tropical Africa, palm oil occupies a predominant position in agricultural production, trade and consumption of fats. More particularly in Benin, oil palm plays an important economic role and is the most productive oil crops. Due to its importance in the economy and food security of rural community, there is nowadays a huge expansion of palm plantations in the country while environmental impacts of this ecosystem is currently a highly controversial topic. As part of the ASEEW@ research project "Assessment of Surface Ecosystem Exchanges in West Africa", funded by 'OWSD Early Career Fellowship', an eddy covariance station has been set up in April 2022 above an oil palm plantation in Dangbo, southeast Benin under a sub-equatorial climate. Meteorological and surface conditions are also acquired continuously at a frequency of one minute at the site. Preliminary results obtained reveal that from the period April 2022 to March 2024, radiation was the main driving variable for daytime CO2 flux while no clear relationship has been yet found between nighttime CO2 flux and its potential driving variables. Overall, daytime CO2 flux averaged -12 µmol.m-2 s-1 and CO2 emissions ~ 8 µmol.m-2 s-1. Water loss through actual evapotranspiration (~ 350 W m-2) in this ecosystem is the dominant term of the surface energy balance.

Keywords: Global warming, oil palm plantation, carbon dioxide, CO2 emissions, water vapor.

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Evaluating optimal release heights from mountain receptors for an improved estimate of methane emissions in Northern Italy

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

The Po valley, situated between the Alps and northern Apennines, is a significant hotspot for air pollution and greenhouse gas emissions. This study aims to quantify methane (CH_4) emissions spatiotemporarily using an observation-based approach i.e. the Bayesian inverse modeling framework FLEXINVERT+ coupled with a Lagrangian transport and dispersion model FLEXPART. FLEXPART is run backwards in time mode, driven by ECMWF ERA5 reanalysis at two different horizontal resolutions. 17 ICOS stations are integrated alongside background information from CAMS and prior emissions to optimize CH_4 fluxes. Challenges arise in accurately representing the complex terrain features of mountain receptors due to the use of coarse resolution windfields of 0.5°x0.5° and 0.2°x0.2°, resulting in the smoothing of the orography, such as mountain slopes and peaks and introduces uncertainties in atmospheric transport modeling. Therefore, optimal particle transport release height is evaluated using sulfurhexafloride (SF_6) as a tracer across four release height scenarios. The optimal choice is determined by matching model with observed equivalent potential temperature to derive the model height (via the hypsometric equation) that best represents the observation. Optimal release heights are calculated hourly. Initial findings indicate that employing varying release heights, as opposed to original sampling height, results in substantial error reduction, e.g., for Zugspitze (ZSF) of approx. 18% to 86% in January and July. This improved the accuracy of the source-receptor relationships and holds promising prospects of achieving improved inversion estimates. Validation of this methodology for estimating optimal release heights and a comparison of posterior increments is presented.

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Reviewing the latest Artificial Intelligence and Eddy Covariance technologies for Comprehensive Flux Monitoring

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

The Eddy Covariance (EC) method is a way to directly and instantaneously observe the exchange of carbon, water, and energy between the Earth's surface and atmosphere. Due to the multiple interconnected data streams and large amount of data involved, EC is well-suited for Artificial Intelligence (AI) applications. This combination of AI and EC is expected to facilitate real-time flux monitoring and hence will likely play a crucial role in achieving the climate change mitigation and adaptation goals set out in the Sustainable Development Goals (SDGs) of Agenda 2030. To support this, we conducted a scoping review that compiled innovative AI techniques used in flux monitoring research over the past two decades. We screened the Machine Learning (ML) algorithms findings in our reviewed works and employed them to: predict, upscale, down scale, and gap-fill flux data. We also find a lack of uniformity in available techniques, due to the diverse technologies and variables employed across environmental conditions and ecosystems. We suggest that future progress in this field requires an international, collaborative effort involving computer scientists and ecologists. We suggest exploring modern Deep Learning (DL) methods like Transformers and generative AI to explore their potential benefits in this domain. A forward-thinking strategy is crucial to effectively harness AI in combination with EC for fluxes monitoring in the context of climate change.

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Global and local climate change impacts on CO_2 exchange from a Scottish peatland.

Karen Yeung[1], Carole Helfter[1], Neil Mullinger[1], Sarah Leeson[1], Mhairi Coyle[1,2], Duncan Harvey[1], Eiko Nemitz[1], Matthew Jones[1], Peter Levy[1]

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Theme

5. Impact of climate extremes on GHG fluxes: understanding driving processes and responses across scales

Abstract Text

Peatlands play an integral role in the global carbon cycle. Their ability to sequester carbon is controlled by numerous, often competing factors including precipitation, temperature and phenology. Long-term datasets are essential to disambiguate natural variability in Net Ecosystem Exchange (NEE) from shorter-term fluctuations.

We present >20 years (2002-2023) of eddy-covariance (EC) measurements of NEE of carbon dioxide (CO2) from Auchencorth Moss (55º47'32 N, 3º14'35 W, 267 m.a.s.l.), an ombrotrophic peatland in central Scotland. Alongside, we report a range of vegetation and meteorological measurements including total solar and photosynthetically active radiation, rainfall, and water table depth (2007+). This dataset is an important resource as the longest-term record of CO2 fluxes from a Northern peatland coupled with a suite of ancillary measurements.

Although a consistent CO2 sink between 2002-2012, net annual losses of CO2 have been recorded frequently at Auchencorth since 2013. In recent years seasonal rainfall patterns have changed, with drier summers and wetter shoulder seasons compared to the long-term trend. We also observe that water table depth plays a crucial role, affecting both gross primary productivity and ecosystem respiration during the growing season. Furthermore, whilst NEE is broadly positively correlated with growing season duration, anomalies in mean winter air temperatures combined with reduced rainfall during spring and summer generally explain annual CO2 sink strength variability.

It is clear that the role of Northern peatlands within the carbon cycle is being modified, driven by changes in climate at local and global scales, reducing the reliability of peatland carbon uptake and storage.

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Advancement of an accurate multi-functional pCO_2 sensor for measurements at depth and air-sea CO_2surface flux determination

Mark Barry, Michael Veenstra, John Paul Sol Cruz, Travis Thompson

Pro-Oceanus Systems, Bridgewater, Canada

Theme

18. Manufacturers' Session

Abstract Text

Accurate determination of CO_2 fluxes across a range of aquatic environments is required for constraining carbon budgets over broad temporal and spatial scales. We describe here a multifunctional pCO_2 sensor that is capable of measuring air-sea CO_2 concentrations as well as having the capability to measure pCO_2 at depths to 600m, all in a single sensor. Providing accurate data with a single sensor across the continuum of aquatic environments enables a new level of carbon budget constraint that is both simple, and reliable. An optional compact calibration gas module has been designed to provide certified reference measurements. The designs are backwards compatible with existing Pro-Oceanus pCO_2 sensors, to minimize costs and amplify the opportunities for equipment use across a multitude of science projects and programs.

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Utilizing Tropomi Satellite Observations for Constraining the Methane Budget over India through Inverse Modeling

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Assessing and quantifying the distribution of greenhouse gas (GHG) fluxes presents a significant scientific challenge today. Current bottom-up based GHG estimates though enhance our understanding of emissions, they are highly uncertain and occasionally they do not reflect actual emissions. In order to constrain the GHG budget and reduce the uncertainties associated with the existing inventories, GHG observations in conjunction with numerical atmospheric models are used. This method is popularly called as Inverse Modeling. A significant barrier in applying this technique, particularly in regions like India, is the limited coverage of ground-based GHG monitoring networks. With the advent of satellite remote sensing technology, however, it is possible to leverage high-resolution satellite data to bridge these observational gaps and better define the GHG budget.

This research utilizes the Bayesian inversion framework, FLEXINVERT (Thompson and Stohl 2014), integrated with the Lagrangian Particle Dispersion Model, FLEXPART (Stohl et al 1998), to incorporate observations of CH4 from the TROPOMI satellite and refine CH4 flux estimates across the Indian region. The FLEXPART model simulates the atmospheric transport of GHGs and generates sensitivity fields that serve as the transport mechanism in the inversion process. Additionally, this study will employ a variety of prior fluxes and background concentration data to enhance the accuracy of the GHG budget constraints over India. The chosen domain while having strong fluxes of CH4, is not well constrained by the existing ground-based measurement networks. The outcomes of this study will be evaluated against the sparse in-situ data available for the area.

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Quantifying Carbon Sequestration in Tidal Wetlands using Eddy Covariance

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Theme

7. Carbon Cycling along the Land Ocean Aquatic Continuum

Abstract Text

The WETCOAST project explores the potential of tidal marshes and mangroves creation as nature-based solutions (NBS) for climate change mitigation and coastal protection. It aims to develop a comprehensive methodology for quantifying carbon sequestration in newly established wetlands.

Within the this project, we will deploy an eddy covariance tower in the Hedwige-Prosperpolder project (Belgium & Netherlands), a large-scale (465 ha) temperate tidal marsh creation effort within the Scheldt estuary. This tower will measure greenhouse gas exchange (CO_2 and CH_4) between the wetlands and atmosphere, while additional studies will quantify carbon fluxes in the water column.

Integrating these air-water fluxes with landscape-scale carbon sequestration quantification, allows to close the whole-ecosystem carbon budget. All data will be integrated to inform the development and validation of a modelling tool, enabling to support the design of NBS projects so they can deliver optimal carbon sequestration and shore erosion protection benefits.

WETCOAST leverages existing ecological data from the region to create a powerful demonstrator showcasing a cost-effective approach to assess long-term carbon sequestration potential in tidal wetlands. This approach will further elucidate the relationship between carbon sequestration and other vital ecosystem services provided by these coastal ecosystems.

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The Norunda Clear-Cut – Towards a Carbon Budget of a Full Forest Rotation Cycle

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

The Norunda site was established in 1994 in the southern boreal forest of Sweden, as one of the first measuring CO_2 fluxes using the eddy-covariance method. The Norunda forest consisted mainly of mature Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*). Since 2018, Norunda is a certified (combined ecosystem and atmosphere) ICOS station, co-located with an ACTRIS station. In autumn 2022, the 100–130-year-old trees within a radius of 300 m from the flux tower were harvested, creating a clear-cut of 30 ha. In spring 2024, soil scarification was finalised and the area was replanted with mainly pine saplings.

In Sweden, the majority of the boreal forest is managed, and rotation forestry with clear-cutting followed by planting of monocultures is the predominant management regime. Yet, the impact of clear-cuts on the forests' carbon budgets is still under discussion. While several studies have compared CO_2 exchanges at clear-cuts and at chronosequences of forests, Norunda offers the unique opportunity to follow a single site through the forest rotation.

We present CO_2 flux data from the mature forest and the first years after the clear-cut. Norunda was a source of CO_2 already before the clear-cut, with annual net ecosystem exchange (NEE) sums of 302±14 g C m^{-2} (mean±se, 2013-2021). As expected, CO_2 emissions increased significantly in 2023, resulting in more than double the annual NEE. As there was hardly any vegetation cover in 2023, the increase was driven by a large drop in gross photosynthesis and a small drop in ecosystem respiration.

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How to leverage measurement redundancy to improve data quality in the ICOS ecosystem network.

Giacomo Labbri, Simone Sabbatini, Giacomo Nicolini, Dario Papale, Adriana Mariotti

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

To ensure temporal data continuity and quality of meteorological measurements, the ICOS ecosystem network standard was conceived to have replicates of key variables, such as air temperature, air humidity, soil temperature, and solar radiation.

Redundant variables are important because, despite thorough attention to reducing gaps in the ground-based meteorological time series, technical issues and bad-quality data can lead to undesired discontinuities. In addition, heterogeneity can affect spatial aggregates of meteorological variables. To understand the potential impacts and correct we developed an approach based on the redundant measurements. We explore statistical and machine-learning techniques to leverage the redundant variables. We employ simple and multilinear regression fits among neighboring instruments to identify and correct data anomalies and gaps. Additionally, we apply a Random Forest algorithm to predict and validate the data outputs from these instruments, ensuring robustness in our approach.

The preliminary results indicate that redundant measurements can significantly improve meteorological data quality and reliability. This methodology helps in maintaining continuous data flow during instrument downtime and enhances the overall integrity and robustness of the ICOS data. This approach can be extended to other observation networks with redundant instrumentations to optimize data coverage and robustness and showcase the advantages of having redundant instruments measuring the same physical variable.

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CO2 Fluxes at High-Altitude mountain ecosystems: a comparative Study of two Grasslands in The Aosta valley

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Theme

4. Processes involved in the greenhouse gas cycle in terrestrial ecosystems

Abstract Text

Mountain ecosystems are known to be particularly sensitive to the effects of climate change. Nevertheless, our understanding of crucial biogeochemical variables, essential to understand how these ecosystems respond to varying environmental conditions, remains incomplete.

In this study, CO_2 flux measurements performed at two high-altitude eddy covariance (EC) sites are compared. The sites are located in Torgnon and Nivolet (Western Alps, Italy), and belong to the ICOS network as Associated stations: IT-Tor and IT-Niv. Both sites are unmanaged subalpine grasslands located at different elevations (2050 and 2750, respectively) and feature distinct species abundances. On average, snow covers these areas from October to May (IT-Tor) and June (IT-Niv), limiting the growing season to approximately four to five months. EC measurements of CO_2 fluxes have been conducted continuously since June 2017 and 2019 at IT-Tor and IT-Niv, respectively. We compared CO_2 fluxes from both sites under similar meteorological conditions to assess their differences from an ecophysiological perspective. Phenology was also considered to estimate the varying responses to extreme weather conditions between the two grasslands. In detail, the response to the 2022 summer drought was explored. The ecophysiological responses of these mountain ecosystems to environmental variations, including altitude, species composition, and past management, will be discussed. Our findings underscore the sensitivity of these ecosystems to climate change, emphasizing the need for continuous monitoring. Moving forward, further research integrating long-term data collection and modeling techniques will be crucial for a more comprehensive understanding of the impacts of climate extremes on mountain ecosystems in Europe.

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Toward a standardized processing of eddy covariance multi-gas flux measurements in urban environments

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Theme

11. Quantification of urban greenhouse gas emissions - from novel monitoring to source identification

Abstract Text

Eddy-covariance flux measurements in urban environments are becoming more and more frequent both due to the importance of these environments for achieving the net zero greenhouse-gas emissions targets, and to the development of new sensors and new knowledge that allow increasingly reliable measurements. However, measuring fluxes in these environments pushes EC measurements to the limit of their applicability due to the complex spatial conformation of urban landscapes and the variety of emission sources. Therefore, a rigorous and standardized data processing becomes essential to ensure high data quality and allow reliable comparisons between different sites and the comparison/integration with estimates from different techniques. In the context of ICOS network we are developing a processing pipeline optimized for the treatment of fluxes in urban environments based on a the widely consolidated method applied to natural ecosystems. In this work, we present some results from the pre-processing of data which mainly concern the quality of the concentration data, the synchronization of the time series of the various measured gases and the wind data, the data screening based on the technique requirements, and the performance of the measurement sensors.

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An unintentional large-scale land use change and restoration experiment promoting a holistic approach: the new Castelporziano research cluster

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Theme

17. Best Practices in the landscape of Research Infrastructures: Cooperation, Co-location and other lessons learned

Abstract Text

The Castelporziano Presidential Estate is a natural reserve with an extension of about 6000 ha, in large part covered by forest that hosts one ICOS Class 1 station (IT-Cp2). In 2017 an insect (Toumeyella parvicornis) started to attack the domestic pine (Pinus pinea L.) and this led rapidly to the death of more than 200 ha of pine forest, with trees older than 100 years. The dead trees have been almost completely removed and the main strategy for the ecosystem restoration will be a reforestation with a mix of deciduous species. Nevertheless, some areas will be left to natural evolution in different conditions (grazing protection, presence of understory etc.) thanks to the availability of the Presidential Estate managers.

This unforeseen large-scale land use change event provides a unique opportunity to the scientific community that, also thanks to two national projects (NBFC and ITINERIS) is creating a new unique long term observatory system, with five eddy covariance towers, multiple samplings and analysis (e.g. soil fluxes and stocks, isotopes, leaf level exchanges, VOCs, vegetation, insects and soil microbiological biodiversity, remote and proximal sensing, SIF). Thanks to the involvement of RIs such ICOS and eLTER this will also create an opportunity where collaboration and integration of different RIs and competences, centralized common services and collocated campaigns will be tested and can provide important information for the future European inter-RIs collaborations. All the data and measurements collected will be open access and interested people are invited to carry on additional experiments and analysis.

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US national fossil CO_2 fluxes for 2010-2020 based on atmospheric radiocarbon measurements

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

Despite inventory-based estimates of fossil-CO2 emissions likely being accurate to within 10% for most developed countries, emissions based on atmospheric measurements can bolster confidence in inventories and provide emissions estimates closer to real time. Because 14C is completely absent from fossil CO2, precise measurements of atmospheric CO2 and its 14C:C ratio can isolate the fossil contribution to observed CO2 gradients. Using a global, but US-focused, measurement and modeling system we will present monthly-resolved fossil-CO2 emissions for different regions in the US between 2010 and 2020. Our estimates from 2010 through 2015 show a significant decrease in US fossil CO2 emissions consistent with, yet independent from, the official national US inventory-based estimates from the EPA. These results show that the eastern third of the US dominates both national emissions and the observed decrease, consistent with inventories which show that US and eastern emissions have decreased since their peak mainly as a result of a transition from coal- to gas-fired power plants. We will compare our 2010-2020 emissions estimates with both the EPA's official US inventory and other bottom-up estimates not used as a priori information in our inverse modeling system. We will also discuss how co-measured short-lived tracers can act as proxies for radiocarbon. Finally, we will discuss the steps required to enhance both the US and global aspects of our system and the extent to which approaches like ours might be applied to regions in other parts of the world, including synergies with the current CORSO project operating within ICOS.

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Improving regional emission estimates over India using satellite measurements

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

The major methane emission sources over India are livestock, rice cultivation, oil and gas systems, coal mining, landfills, wastewater treatment, wetlands etc. The short lifetime and large global warming potential qualifies methane as an important mitigation target in the context of climate change. The available bottom up inventory information regarding methane emissions over the Indian region is associated with significant uncertainty which calls for the aid of observational and model simulations for better understanding of the same. Here, we use the column-averaged dry-air mixing ratio of methane (XCH_4) from TROPOMI (TROPOspheric Monitoring Instrument) on the ESA Copernicus Sentinel-5 Precursor satellite to infer India's CH_4 emissions. We analyse the potential of these retrievals to quantify methane emission hotspots and to improve the emission estimates over the Indian subcontinent. Weather Research Forecast model coupled with Chemistry (WRF-Chem-GHG) simulations has been used for the forward transport simulations of atmospheric methane. A comparative study between the observation and model simulations give an idea of the uncertainty over the Indian region. The inversion studies introduced will enable us to improve the existing anthropogenic emission estimates available in the Indian region.

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Consistency between the spatial representativity of space-borne observations and of ground-based eddy covariance measurements

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

The eddy-covariance technique (EC) is commonly used for continuously measuring carbon, water and energy fluxes at high temporal resolution between the ecosystems and the atmosphere. The area which the measured fluxes refer to (footprint) has a spatial resolution varying from a few to hundreds of meters from the measuring point along-wind and from a few to tens of meters crosswind. Space-borne, or remote sensing, observations are used to map spectral vegetation indices over large scales and are increasingly available at ever higher spatial (up to 1 m) and temporal (up to daily) resolutions. One of the most common uses of this data is in combination with the EC data in order to estimate carbon and water fluxes over larger areas. The requirement behind this upscaling exercise is that what is measured by EC and what is “seen” by satellites is in agreement, meaning that the spatial representativity of the two measures is consistent. This could be a challenge, especially over heterogeneous surfaces. In addition, the dynamic nature of the footprint makes things more complicated as it can include different surfaces at different time scales. By using the data provided by the ICOS network, we performed an unsupervised landscape clustering at different spatial scales by using different algorithms, computed the EC towers’ footprints at half-hourly resolution and assessed the vegetation clusters within it, and then compared these spatial features in order to evaluate their consistency and its temporal evolution.

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The CROP2021 dataset: a unique and consistent dataset to estimate and monitor carbon budget of European croplands

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Theme

9. Combining data and models to improve estimates of regional to global GHG budgets and trends

Abstract Text

The CROP2021 initiative aims to collect standardised fluxes (NEE, GPP, Reco), meteorological data (from ICOS-WINTER 2020 release and new ad hoc data collections), management data (field operation types, yields, fertilizer application types, amounts and dates, etc.) and ancillary data including soil and vegetation properties data (from in situ or satellite observations). Each category of data was checked using a visual inspection and a set of statistical and objective quality criteria. Management and ancillary data, absolutely critical to interpret carbon fluxes, were compiled and standardised (variable names, unit expression, lexicon). The dataset covers 14 crop sites and 163 crop site-years, 26 crop species, from 2001 to 2021 across Europe and different pedo-climatic contexts.

This specific dataset was built to answer five objectives: (1) Analyse the interacting effects of heterogeneous meteorological conditions and management intensity on the Net Ecosystem Carbon budget and total greenhouse gas (including emissions related to field operations) budget of croplands (NECB and GHGB respectively); (2) Develop empirical approaches based on remote sensing and flux data for gapfilling or forecasting; (3) Evaluate and improve the SAFYE-CO2 model for the flux sites, for mapping CO2 fluxes (GPP, Reco, NEE) and carbon budgets; (4) Analyse the effect of management and climate on albedo dynamics; (5) Design, build and test the ICOS protocol for management and disturbance data collection and the BADM system to collect ancillary data.

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Advances and Applications of Tunable Infrared Laser Direct Absorption Spectroscopy (TILDAS) in Atmospheric Gas Quantification

Scott Herndon

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Theme

18. Manufacturers' Session

Abstract Text

Tunable Infrared Laser Direct Absorption Spectroscopy (TILDAS) is a robust analytical method characterized by its rapidity, sensitivity, and selectivity, ideal for quantifying various atmospheric gases. This presentation will commence with a concise overview of TILDAS, its operational principles and the technology. Following this, the presentation will delve into recent advancements and applications.

A focal point will be the novel application of TILDAS in detecting molecular hydrogen (H2), an indirect greenhouse gas. This segment will explore the implications of this capability in environmental monitoring and climate change studies. Additionally, we will present recent findings on the quantification of methane (CH4) and nitrous oxide (N2O) fluxes.

Furthermore, the presentation will cover the application of TILDAS in quantifying 17O in CO2 derived from carbonate samples, an innovative approach that is proving instrumental in paleoclimate research. This method offers enhanced accuracy in reconstructing past climate variations, thereby providing deeper insights into historical climate dynamics.

This session aims to not only outline the technical enhancements of TILDAS but also to underscore its increasing significance in environmental science, particularly in tracking and studying greenhouse gases and their long-term effects on the planet.