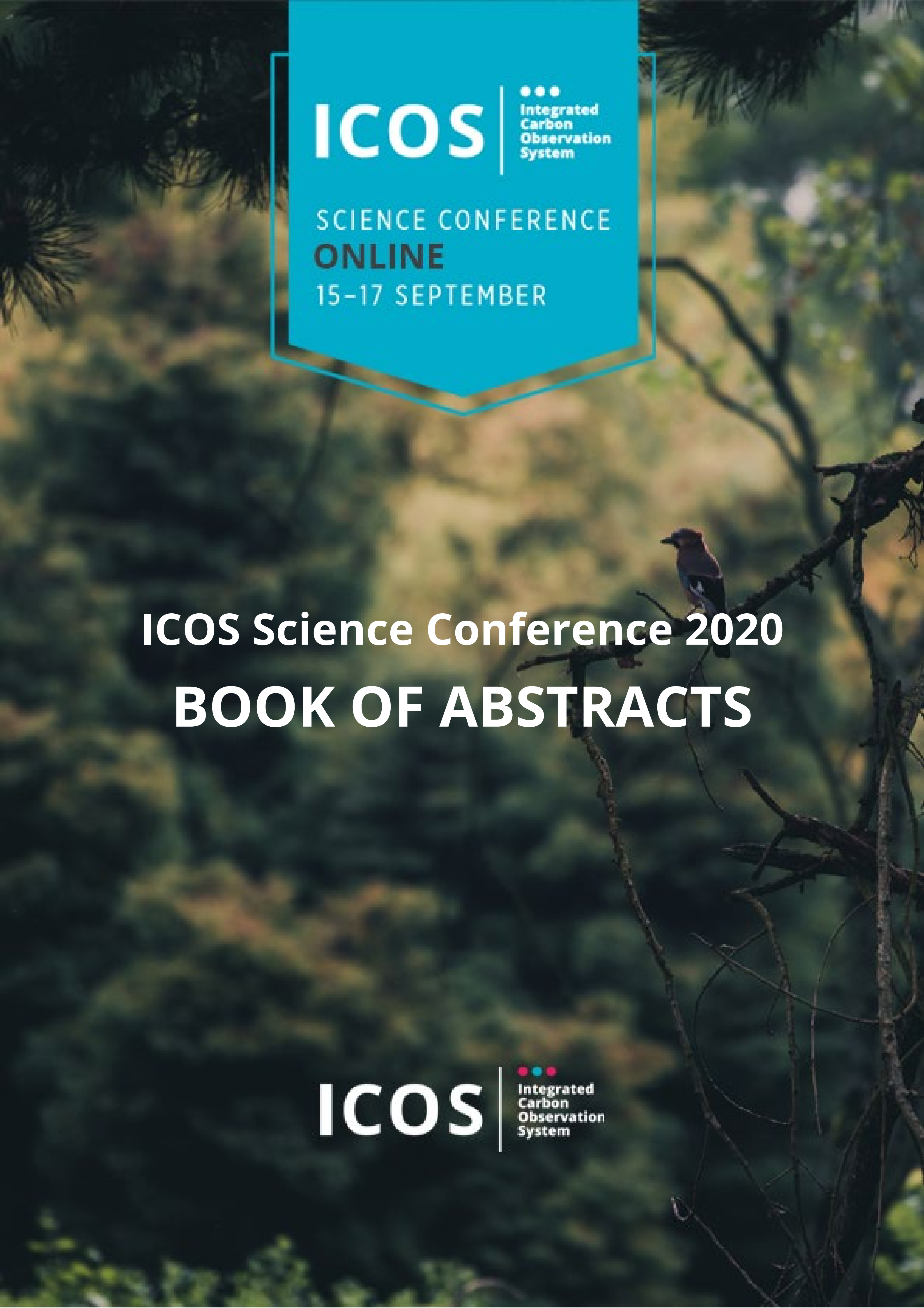


ICOS | Integrated Carbon Observation System

SCIENCE CONFERENCE
ONLINE
15–17 SEPTEMBER

ICOS Science Conference 2020

BOOK OF ABSTRACTS

ICOS | Integrated Carbon Observation System

Contents

ICOS in Short

The Integrated Carbon Observation System, ICOS is a distributed European-wide research infrastructure producing high-precision data on greenhouse gas concentrations in the atmosphere, as well as on carbon fluxes between the atmosphere, earth and oceans. This is important because globally the amount of greenhouse gases in the atmosphere is rising continuously, causing the climate to change. The greenhouse gases flux between the ecosystems, atmosphere and oceans, and are transported in the atmosphere for thousands of kilometres, for example, from densely populated areas to the arctic.

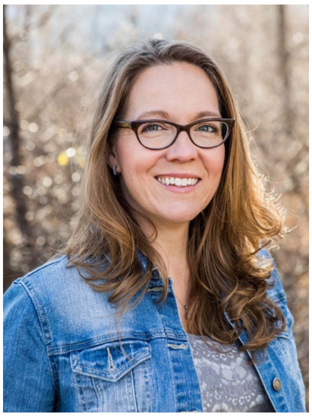
ICOS provides standardised and open data from over 140 measurement stations across 12 European countries. ICOS data is used by scientists who seek to understand this Earth System and by various governmental bodies and international organisations that need science-based and relevant information on greenhouse gases in their decision making, and in efforts to mitigate the consequences of climate change. ICOS consists of more than 500 scientists, who participate in ICOS related work and operations. These scientists, both in the current member countries and beyond, form the ICOS community. They design, build and operate ICOS stations, but even more importantly, process and use the ICOS data while fitting complex models on it. They publish scientific papers, participate in workshops and conferences, and develop new measurement methods.

The community, as ICOS itself, has three fields; ecosystem, atmosphere, and ocean. Each of these also has strong connections to colleagues and operators outside ICOS. At the moment ICOS community includes over 80 scientific organisations, renown universities or institutes - many of which are leaders in their fields. The biannual ICOS Science Conference gathers more than 300 scientists to discuss the scientific topics around greenhouse gas measurement and climate change. The themes of the conference vary from purely scientific sessions to ones related to the Paris Agreement and other policy making.

Plenary Speakers

To be updated as biographies are submitted

Arlyn Andrews



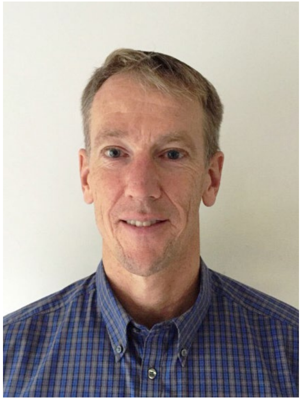
Arlyn Andrews leads the Carbon Cycle Greenhouse Gases group within NOAA's Global Monitoring Laboratory. She has measured carbon dioxide from Earth's surface to the stratosphere from a variety of diverse platforms, including NASA's ER-2 aircraft -- a modified U-2 spy plane, high-altitude balloons, and very tall broadcast towers. Arlyn earned her Ph.D. in Earth and Planetary Science from Harvard University in 2000 and then spent a few years at NASA Goddard Space Flight Center, where she contributed to the initial development of concepts for active and passive CO2 satellite sensors.

Arlyn joined the NOAA Global Monitoring Laboratory in 2003 and assumed responsibility for in situ measurements from tall towers within the NOAA Global Greenhouse Gas Reference Network. She developed the NOAA's CarbonTracker-Lagrange regional modeling framework for estimating greenhouse gas emissions and removals, with a particular emphasis on understanding uptake of carbon dioxide by terrestrial ecosystems. Arlyn has been an active participant in the U.S. Interagency North American Carbon Program since its inception. She served on the Climate Variability and Change panel supporting the Decadal Survey for Earth Science and Applications from Space (ESAS 2017), and she is a member of the

NASA Carbon Monitoring System Science Team and the NASA Orbiting Carbon Observatory Science Team.

Andrews plenary talk will discuss development towards an International Reference Network for Greenhouse Gases

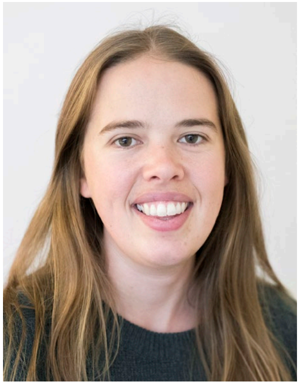
Erik Andersson



Dr Erik Andersson is working at the European Commission's Copernicus Unit, seconded there by the European Centre for Medium-Range Weather Forecasts (ECMWF). While on secondment, Andersson is working on developing Copernicus Services for the monitoring of carbon dioxide (CO_2) emissions, focusing on anthropogenic fossil fuel emissions in the context of the Paris Agreement. The CO_2 monitoring and validation service will be based on satellite and in-situ measurements. Andersson has a scientific background in data assimilation, the global observing systems, the impact of observations on the quality of forecasts and the use of observations in Numerical Weather Prediction (NWP).

Andersson's plenary talk will discuss the requirements for in-situ observations to support the Copernicus CO_2 monitoring service focusing on anthropogenic CO_2 emissions.

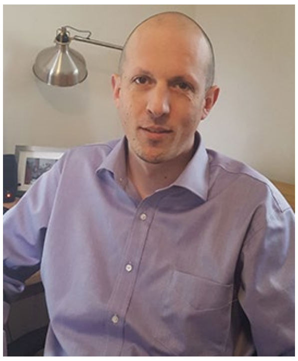
Julia Kelly



Julia Kelly is a PhD student in Environmental Science at the Centre for Environmental and Climate Research at Lund University, Sweden. Her research is exploring new ways to model and upscale carbon fluxes using remote sensing data from ground-based sensors, unmanned aerial vehicles (UAVs) and satellites. She is especially interested in thermal infrared cameras and in understanding how spatial heterogeneity across an ecosystem affects our ability to model and upscale carbon fluxes.

Kelly's plenary talk will be about thermal cameras: a new tool for modeling and upscaling ecosystem respiration?

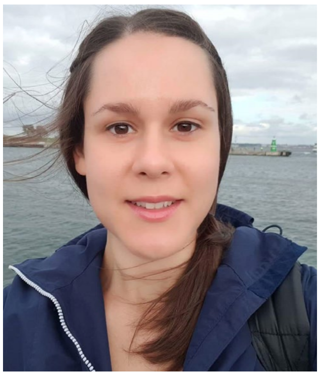
Thomas Lauvaux



Dr Thomas Lauvaux is a Make Our Planet Great Again (MOPGA) research laureate at the Laboratoire des Sciences du Climat et de l'Environnement (LSCE) in France and an affiliate at the Penn State University in the USA. He holds a PhD in atmospheric and climate sciences, and is specialised in data assimilation and mesoscale modeling applied to carbon cycle science. Lauvaux's current research focuses on developing atmospheric assimilation systems at both regional and urban scales to measure fossil fuel emissions from large metropolitan areas and sources and sinks over continents. He is also an active member of the NASA's Orbiting Carbon Observatory (OCO-2/3) mission science team.

Lauvaux's plenary talk will discuss about an uncertainty-based analysis on constraining continental carbon exchanges from atmospheric greenhouse gas mixing ratios.

Karolina Pantazatou



Karolina Pantazatou is a Junior Scientific Programmer at ICOS Carbon Portal, Lund University. She holds a BSc in Informatics and a MSc in Geo-informatics. She has worked as a project assistant, a scientific programmer and a GIS engineer in various interdisciplinary projects focusing on climate change, remote sensing, spatiotemporal demographic analysis and city planning. She has held workshops on how to use GIS-tools and Python-programming for researchers, PhD students, science centre pedagogues, high school teachers and high school students. She is a firm believer of the idea that knowledge has no value unless it is shared, therefore, she strives to create programming tools that are easy to comprehend, use and modify.

Pantazatou's plenary talk will be about presenting ICOS data in education.

Roxanna Petrescu

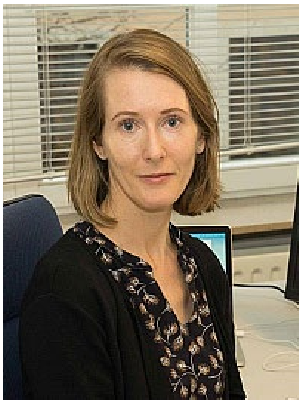
Dr. A.M. Roxana Petrescu is an environmental researcher at the Vrije Universiteit Amsterdam, The Netherlands. She holds a Ph.D. in environmental sciences/hydrology on modelling CH4 emissions from natural wetlands. She has more than 10 years of environmental research experience related to data analysis of greenhouse gas emissions (CO2, CH4 and partly N2O). She has expertise in both bottom-up modelling and emission inventory calculation and verification methodologies. Current research in the VERIFY H2020 project (https://verify.lsce.ipsl.fr/) focuses on reconciliation and assessment of different models and tools leading to verification of GHG inventories by synthesising observation-based estimates of GHG fluxes and carbon stocks from bottom-up, top-down and global emissions databases (e.g. EDGAR, FAOSTAT) to deliver products for comparison purposes and reconciliation with official country level UNFCCC national GHG inventories. She is, as well, leading the GCP-RECCAP2 regional (European) GHG budget synthesis.

Mahesh Kumar Sha

Dr. Mahesh Kumar Sha is working as a scientist at the Royal Belgian Institute for Space Aeronomy (BIRA-IASB) in Belgium. He holds a PhD in Physics and is specialised in remote sensing using Fourier transform spectrometers in the infrared (FTIR) range for the study of atmospheric trace gases. He also is experienced in instrument characterisation and operation, data retrieval, geophysical data exploitation and satellite validation. He has actively participated in several international field campaigns focusing on satellite validation, greenhouse gases emission estimates and the intercomparison of FTIR instruments. He is responsible for the TCCON measurements and the atmospheric ICOS station on La Réunion Island. He is a member of several ground-based FTIR networks, namely, TCCON, COCCON and NDACC. He is part of ESA's S5P Mission Performance Centre (S5P MPC) Routine Operations Validation Service, where he coordinates the operational validation of the S5P methane product.

Sha's plenary talk will be about measurements of greenhouse gases from ground-based remote sensing and in-situ instruments and their application for satellite validation.

Rona Thompson

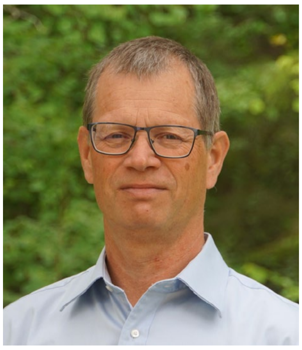


Thompson completed a PhD in Atmospheric Chemistry at Victoria University of Wellington, New Zealand, in 2005. Following her PhD, she held two post-doctoral positions, first at the Max-Planck Institute for Biogeochemistry in Germany, and then at the Laboratoire des Sciences du Climat et l'Environnement in France.

Since 2011, Thompson is a senior scientist at the Norwegian Institute for Air Research, where her research is focused on the estimation of sources and sinks of various greenhouse gases using atmospheric observations. Specifically, she uses the atmospheric inversion approach and has applied this to studying the fluxes of CO2, CH4 and N2O, as well as to the emissions of synthetic trace gases. Thompson serves on the IG3IS steering committee and is a co-leader of the Global Carbon Project N2O budget. She is also an author on the IPCC AR6.

Thompson's plenary talk will be on changes in net ecosystem exchange over Europe during the 2018 drought.

Lars Tranvik



Prof Dr Lars Tranvik is a professor at the Uppsala University, Sweden. He holds a PhD in limnology. Tranvik's research has developed from aquatic microbial ecology, in particular the role of heterotrophic bacteria in food webs and as consumers of dissolved organic matter, to a broader focus on the carbon cycle of inland waters, and the control of the persistence and decay of organic matter across aquatic and terrestrial habitats. Tranvik's recent research is focused on how terrestrial organic matter is transformed in the water column resulting in a subsidy to aquatic food webs, a sediment carbon sink, and emission of carbon dioxide and methane to the atmosphere.

Tranvik's plenary talk will be about the carbon fluxes at the land-ocean-atmosphere continuum.

Mousong Wu

Dr. Mousong Wu is currently working at International Institute for Earth System Science (ESSI), Nanjing University, China, with focus on carbon cycle data assimilation using a generic biosphere model (BEPS) combining multiple sources of observations including remote sensing measurements and in-situ ones at various scales to disentangle the carbon cycling under changing climate from historical to future periods. He is leading two projects on data assimilation in China as an independent PI and also participating in the National Key Research and Development Program of China which focuses on developing a higher resolution carbon assimilation system in China.

His research interests include carbon cycle data assimilation, soil hydrology, cold regions hydrological and biophysical modeling, and agricultural water resources management.

Wu's plenary talk will be about using SMOS soil moisture data combining CO2 flask samples to constrain carbon fluxes during 2010-2015 within a Carbon Cycle Data Assimilation System (CCDAS)

Abstracts of the plenary speakers

To be updated as they are submitted

Towards an International Reference Network for Greenhouse Gases

Arlyn Andrews1, Andrew Crotwell1,2, Ed Dlugokencky1, Kirk Thoning1, Colm Sweeney1, John B. Miller1, Kathryn McKain1,2, Gabrielle Pétron1,2, Bradley Hall1, Steve Montzka1, James W. Elkins1, Dale Hurst,2, Pieter Tans1

NOAA's Global Greenhouse Gas Reference Network (GGGRN) was established to advance and harmonize high quality measurement protocols across scales, platforms and GHG species across the NOAA Global Monitoring Laboratory. The GGGRN includes our cooperative global whole-air sampling network, in situ measurements from surface and tower sites, and vertical profile measurements from aircraft and balloons. The major long-lived greenhouse gases, CO2, CH4 and N2O, are measured, along with minor greenhouse gases and stratospheric water vapor. A large suite of isotopes, halocarbons, hydrocarbons and other trace gases are also measured to provide additional observational constraints on GHG sources and sinks.

The term "reference network" was chosen to emphasize the quality and traceability of the measurements as well as the long-term stability of the network. The WMO Global Atmosphere Watch Global Greenhouse Gas Measurement Techniques community has a long history of promoting these objectives, and the concept of an international reference network for greenhouse gases is timely, as new remote sensing approaches and networks of inexpensive sensors are rapidly emerging with a wide range of measurement objectives and quality.

At NOAA, we are working to document measurement protocols, to comprehensively quantify the uncertainties of our greenhouse gas measurements, and to identify and reduce systematic errors through laboratory tests along with cross-laboratory and intra-laboratory comparisons of standards and field measurements using a variety of approaches. We will present examples of ongoing challenges and progress from NOAA's GGGRN along with a proposal to develop general certification criteria for any lab to produce measurement results that could be considered part of the global reference network. An important goal of our reference network effort is to work with partners across the community to develop and implement strategies that maximize the complementarity of satellite and in situ observations for tracking trends and variability from local to global scales.

Can we see a covid-19 impact in atmospheric GHGs? A diagnostic assessment using STILT

Christoph Gerbig (BSI, MPI-BGC, Jena, GERMANY), Saqr Munassar (MPI-BGC, Jena, GERMANY), Santiago Botia B. (MPI-BGC, Jena, GERMANY), Thomas Koch (Deutscher Wetterdienst, Hohenpeissenberg, GERMANY), Dagmar Kubistin (Deutscher Wetterdienst, Hohenpeissenberg, GERMANY), Michel Ramonet (LSCE, Gif-sur-Yvette, FRANCE), Ute Karstens (ICOS-CP, Lund, SWEDEN)

Many countries introduced a severe lockdown during the initial outbreak of the covid-19 pandemic. Related to reduced traffic, industrial activities, and power generation, a drop in CO2 emissions related to the lockdown has been estimated to 4.3% during the first quarter of 2020 as compared to 2019 (Liu et al., 2020, https://arxiv.org/abs/2004.13614). As the reduction in emissions typically occurred after lockdown measures were introduced in late February or March, the drop in emissions was several times larger on a weekly time scale. Such large emission reductions provide a unique opportunity to assess the capacity of atmospheric GHG monitoring systems to independently detect and quantify GHG emission reductions as targeted with the NDCs (nationally determined contributions). Given the 40% reduction in GHG emissions for the 2021-2030 period promised in the European Union's first NDC as submitted to the UNFCCC in 2016, the covid-related reduction within the first quarter is comparable to average annual reductions envisioned in the NDC. Due to the large variations in atmospheric GHG mole fractions observed at ICOS sites related to synoptic transport variations and biospheric fluxes, we use a combination of recent atmospheric data (ICOS latest data releases, including near real-time data, and datasets collected by the ICOS Atmospheric Thematic Centre in the Drought-2018 initiative) and model results from the atmospheric transport model STILT, coupled with emission estimates and biosphere-atmosphere exchange. By using anthropogenic emissions from EDGAR V4.3, updated to 2019 using the PB statistical review of world energy, and extrapolated to 2020, simulated mole fractions will not show any covid-related reductions. The paper will compare differences between observed and simulated mole fractions of CO2, CH4 and CO for multiple years to those of the current year, and assess the significance of any covid-19 related GHG signals for various sites, different time periods, and different emission sectors.

CarboCity project – A novel quantification and description of urban biogenic fluxes

Leena Järvi (INAR, University of Helsinki, FINLAND), Liisa Kulmala (Finnish Meteorological Institute, Helsinki, FINLAND)

In response to the climate emergency, several cities pursue for carbon neutrality in the upcoming decades. To reach this ambitious goal, all possible means from reducing carbon emissions to maximizing carbon sequestration and storage to urban vegetation and the soil beneath need to be harnessed. Carbon sequestration to vegetation and soils is one of the most efficient natural mechanisms to remove carbon from the atmosphere and as urban green space offers also multiple other societal and ecological benefits, increasing carbon sinks to urban vegetation appears as attractive mean to mitigate climate. There is evidence that the response of urban photosynthesis and soil organic content to environmental conditions differs from those in natural ecosystems but no systematic evidence on their variability and differences exists nor in their correct description in ecosystem and soil models.

The Academy of Finland funded CarboCity project (2019-2023) aims to fill in these knowledge gaps by 1) quantifying carbon storages and flows in different urban green space in different parts of the world including Helsinki, Beijing, London and Sao Paolo, and 2) finding optimal practical planning solutions for maximising these storages in the future. As part of the project, an extensive measurement campaign to quantify the special characteristics of tree ecophysiology and decomposition of soil organic matter in urban green area will be conducted in the vicinity of the ICOS Associated Ecosystem station (FI-Kmp) in Helsinki during summers 2020-2021. During the measurement campaign, leaf and soil gas exchange using chambers and sap and sap flow analysers, and soil carbon storage from urban forest, park and street trees will be collected in order to understand better their environmental response including impacts from potential stress. These measurements will be combined with the eddy covariance measured carbon dioxide and carbonyl sulphide (COS) in distinguishing the photosynthetic signal from the net exchange of CO2 over mixed land use. The purpose of this study is to describe the first results of the measurement campaign. Later on, these data will be combined to parameterisations to be used in land surface model SUEWS and soil carbon model Yasso.

Thermal cameras: a new tool for modeling and upscaling ecosystem respiration?

Julia Kelly (Centre for Environmental and Climate Research, Lund University), Natascha Kljun (Lund University, Lund, SWEDEN), Lars Eklundh (Lund University, Lund, SWEDEN), Bengt Liljebladh (Lund University, Lund, SWEDEN), Leif Klemedtsson (University of Gothenburg, Gothenburg, SWEDEN), Per-Ola Olsson (Lund University, *Lund, SWEDEN), Per Weslien (University of Gothenburg, Gothenburg, SWEDEN), Xie Xianghua (Swansea University, Swansea, UNITED KINGDOM)*

Networks of spectral sensors and cameras have been established at ICOS sites to study a range of ecosystem processes from gross primary productivity (GPP) to phenology, and help bridge the scale-gap between in-situ and satellite data. However, there have been few attempts to use these technologies to study ecosystem respiration (ER). Temperature is one of the main driving factors of ER and can be measured at high spatial and temporal resolution using thermal infrared cameras. Thermal cameras capture images of surface temperature, i.e. the temperature felt by plant canopies and the soil surface, which can depart significantly from standard air or soil temperature measurements. One of the main advantages of using thermal imagery is that it can provide detailed spatial temperature data across whole ecosystems, whereas soil and air temperature are usually only measured at a few points across a site.

We tested the feasibility of using thermal cameras mounted on a tower and on an Unmanned Aerial Vehicle (UAV) to model and upscale ecosystem respiration at a peatland in southern Sweden. The tower-based camera recorded images every 5 minutes, and viewed 6 collars used for manual CO_2 efflux measurements over two summers (2018 and 2019). Soil temperature was also measured for each collar during CO_2 efflux measurements whilst air temperature was measured 60m away from the collars. The collars were divided evenly between the two main vegetation microforms at the site: Sphagnum-dominated hollows and vascular plant-dominated hummocks. Using the CO_2 measurements, we compared the accuracy of an ER model driven by surface temperature to when it is driven by soil and air temperature. All model expressions yielded similar accuracies, and when averaged over the whole growing season, surface temperature-derived ER estimates varied by <20% compared to air temperature. Consequently, we used the ER model based on surface temperature, along with images captured from the UAV, to upscale ER over a larger area of the peatland. Our results represent the first high resolution (<10 cm) maps of ER.

We also investigated the effect of the 2018 hot drought on our ability to model ER, and found that the temperature-sensitivity of the ER model was dependent on the choice of temperature metric (soil, air or surface) and vegetation microform. In most cases however, ER stopped increasing at high temperatures, showing the importance of choosing a model shape that captures this response to avoid overestimating ER. Finally, the ER of both microforms declined during the hot drought, but more so for hummocks than hollows (-48% and -15%, respectively). Vegetation heterogeneity should thus be accounted for when modelling and upscaling ER.

Presenting ICOS data in education

Karolina Pantazatou (Physical Geography and Ecosystem Science, ICOS Carbon Portal, Lund University, SWEDEN) Harry Lankreijer (Physical Geography and Ecosystem Science, ICOS Carbon Portal, Lund University, Lund, SWEDEN), Lars Eklundh (Physical Geography and Ecosystem Science, Lund University, Lund, SWEDEN), Jutta Holst (Physical Geography and Ecosystem Science, ICOS Sweden; Lund University, Lund, SWEDEN), André Bjärby (Physical Geography and Ecosystem Science, ICOS Carbon Portal; Lund University, Lund, SWEDEN)

The Swedish Education Board promotes the teaching of programming at secondary high school level. In a cooperation between Swedish Science Centres, Lund University and ICOS Carbon Portal, notebooks were developed to introduce basic programming in Python. The aim was to show how programming is used to analyse large amounts of data in relation to climate change. Data from ICOS are used to explain the carbon cycle, how to analyse changes of atmospheric CO2 concentration and the effects of drought on the carbon balance. The notebooks can be run in Jupyter, as well as in Google CoLab. The material is today available for all through ICOS Carbon Portal and GitHub. The notebooks are used in two different ways: as teaching material for teachers at secondary schools and as part of interactive exhibitions hosted at the Swedish Science Centres for both the general public and visiting high school students. In the examples we use data from the Swedish ICOS stations Hyltemossa and Svartberget. The notebooks can easily be adapted to use data from other measurement stations.

A synthesis of European greenhouse gas emissions and their uncertainties

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Studies (NIES), Ibaraki, JAPAN), Arjo Segers (TNO, dep. of Climate Air & Sustainability, Utrecht, NETHERLANDS), Misa Ishizawa (National Institute for Environmental Studies (NIES), Ibaraki, JAPAN), Yi Yin (California Institute of Technology, California Blvd, Pasadena, UNITED STATES), Bo Zheng (Le Laboratoire des Sciences du Climat et de l'Envi, Gif-sur-Yvette CEDEX, FRANCE), Richard Houghton (Woods Hole Research Centre (WHRC), Falmouth, UNITED STATES), Giuseppe Etiope (Istituto Nazionale di Geofisica e Vulcanologia, Rome, ITALY), Chris Wilson (University of Leeds, Leeds, UNITED KINGDOM), Giulia Conchedda (Food and Agriculture Organization FAO, Rome, ITALY), Han Dolman (Department of Earth Sciences, Amsterdam, NETHERLANDS)

Emission of greenhouse gases (GHGs) and removals from land, including both anthropogenic and natural fluxes, require reliable quantification, including estimates of uncertainties, to support mitigation action, especially under the Paris Agreement. This study updates Petrescu et al., 2020 and provides a state-of-the-art scientific overview of bottom-up and top-down anthropogenic and natural GHG emissions data from all IPCC sectors in the European Union and UK (EU27+UK). The data integrates recent scientific emission inventories with ecosystem data and process-based models and summarizes their emissions and removals over the period 1990-2018, as part of the first data analysis year (2019) of the VERIFY project. Bottom-up and top-down products are compared with European national greenhouse gas inventories (UNFCC NGHGI 2019) aiming to improve the overall estimates of the GHG emissions in Europe and assess the differences between estimates. Whenever available, uncertainties and their propagation within multiple sources are reported. Uncertainty in both NGHGI and other approaches remains defined as the spread around a model estimate, given that the true emissions are unknown. While UNFCCC NGHGI 2019 data for EU27+UK provides quantification of uncertainty following the established IPCC guidelines and based on varying the parameters of inventory calculations, uncertainty in estimates produced with other methods like ensembles of atmospheric inversion top-down models (TD) or bottom-up models (BU) arise from both within model uncertainty and spread from different estimates in an ensemble (if available). In comparing NGHGI with other approaches and for their consistency, a key source of uncertainty are the different sectors covered by each approach, e.g. anthropogenic and natural fluxes. Regarding BU estimates including NGHGI, our findings at EU27+UK level, show that uncertainties are mainly related to inconsistencies and differences triggered by methodological changes and updates used for calculating emissions and removals. Similar to the findings in Petrescu et al., 2020, the activity input data (AD) plays as well an important role, creating large differences between NGHGI and other BU emissions, (e.g. 20 % for agriculture). Regarding TD estimates, the comparison with NGHGI is highly uncertain. As TD inversions cannot distinguish between all emission sectors used by NGHGI and report either total emissions or a coarse sectorial partitioning, their comparison to NGHGI is sensitive to the post-processing of inversions for removing non-anthropogenic fluxes not accounted for in NGHGI (e.g. CH_4 emissions from natural wetlands, lakes and geological sources, emissions from imported biofuels). For example, for CH_4 we found that the min-max range of all inversions covers the UNFCCC NGHGI estimates, with the median of VERIFY inversions being in 2017 14.8 % larger than the UNFCCC NGHGI, while the medium of non-VERIFY inversions 27.5 % smaller than the UNFCCC NGHGI.

This comparison is a first attempt and is meant to be seen as an important message to the NGHGI for introducing in their reporting the natural sources. Because TD modelling is a mass-balance approach which provides information from the integrated emissions from all sources, the verification with BU inventories and reconciliation with TD estimates should be done for areas best constrained by atmospheric observations.

Carbon Cycling along the GB Land Ocean Aquatic Continuum (LOAC)

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The ICOS research infrastructure is established around a conceptual model of the global carbon (C) cycle consisting of carbon fluxes between the atmosphere and the land surface, and from the atmosphere to the ocean. Atmospheric CO_2 is accumulating at a rate of approximately 5 Gt C yr-1 ,with the difference between emissions and this accumulation believed to be entering the ocean and the terrestrial biospheres. The other major flux in this system, 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. The uncertainty in this term is substantially caused by challenges in defining the large number of steps associated with this flux which include 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; consisting of 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, the dominant processes driving them and their past changes. One such environment is Great Britain (GB), a large temperate island in the Northern Hemisphere with spatial variation in population intensity, underlying geology, terrestrial organic carbon deposits, agricultural development and forestry located in a shallow coastal shelf sea that links through to the open ocean. Over the last 5 years multiple field programmes have worked on the C Cycle within the GB LOAC to deliver a dataset including organic and inorganic carbon concentrations in rivers and estuaries draining diverse landscapes. In this contribution we will describe the breadth of this field programme, present selected highlights from each sector, and attempt to bring the data together to estimate the ultimate fate of the C emitted from the GB landscape and the factors which control this.

Measurements of greenhouse gases from ground-based remote sensing and in-situ instruments and their application for satellite validation

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(University of Bremen, Bremen, GERMANY), Qiansi Tu (Karlsruhe Institute of Technology, Karlsruhe, GERMANY), Damien Weidmann (Rutherford Appleton Laboratory, Didcot, UNITED KINGDOM)

The atmospheric concentration of greenhouse gases has been steadily increasing in recent years due to anthropogenic activities. Continuous monitoring of precise and accurate measurements of these gases is of utmost importance to determine their sources and sinks, and trends. In recent years, satellite based remote sensing measurements have been able to provide a global measurement coverage of these gases. The nadir looking satellites detecting scattered sunlight in the near-infrared spectral region provide the most powerful method for global mapping of these gases. These measurements cover the whole atmospheric column therewith providing the total column concentrations of the trace gases. However, satellite measurements require accurate validation. Such accurate reference measurements can be performed from surface based, air-borne or already validated satellites. To ensure equal dependency on the measurement parameters, the best validation method for the satellite data is to use the total column amounts of these gases calculated from the solar absorption measurements performed from the surface and satellites in the same spectral region.

The Total Carbon Column Observing Network (TCCON) has been the baseline ground-based network for measuring accurate and precise column-averaged dry air mole fractions of CO2, CH4 and CO amongst other gases. However, the number of stations (currently ~25) is limited and has a very uneven geographical coverage. To improve the satellite validation and better contribute to the carbon cycle science studies, a denser distribution of ground-based solar absorption measurements is needed to cover geographical gaps for various atmospheric conditions (humid, dry, polluted, presence of aerosol, varying surface albedo) and to create a large latitudinal distribution. For this reason, several groups are investigating portable low-cost instruments, which can complement the existing networks and thus enhance the validation of satellite measurements.

The “Fiducial Reference Measurements for Ground-Based Infrared Greenhouse Gas Observations (FRM4GHG; http://frm4ghg.aeronomie.be/)” campaign has been funded by the European Space Agency (ESA) to characterize the performance of several low-cost portable spectrometers for precise solar absorption measurements of CO2, CH4 and CO. These measurements were performed next to the TCCON instrument and ICOS station at Sodankylä for three years as of 2017 and with one of the instruments measurements were performed at the TCCON sites in Australia during 2019. In addition, regular AirCore launches were performed from the Sodankylä site to provide in-situ reference profiles of these gases; this is useful for the verification of the instrument calibration. The intercomparison results show that the tested low-resolution instruments provide high quality data comparable to that of TCCON. The data collected during the campaign were used for satellite validation.

The results of the campaign will be presented with an overview of the accuracy and precision achieved by each instrument and the results of the satellite validation. We show the benefits of the portable FTIR remote-sensing instruments by means of a few example cases.

Changes in Net Ecosystem Exchange over Europe During the 2018 Drought Based on Atmospheric Inversions

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The 2018 drought was one of the worst European droughts of the 21st century in terms of its severity, extent and duration. The effects of the drought could be seen, in particular, in a reduction in harvest yields in parts of Europe, as well as an unprecedented browning of vegetation in summer. Here, we quantify the effect of the drought on Net Ecosystem Exchange (NEE) using five independent regional atmospheric inversion frameworks (PyVAR-CHIMERE, CarboScope-Regional, LUMIA, FLEXINVERT and NAME). Using a network of atmospheric CO_2 mole fraction observations, we estimate NEE with at least monthly and 0.5°×0.5° resolution for 2009-2018. We find that the annual NEE in 2018 was likely more positive (less CO_2 uptake) in Europe compared to the mean of the last 10 years, and that the summer NEE was very likely more positive than the summer mean of the last 10 years. The positive NEE anomalies coincided spatially and temporally with negative anomalies in soil water and were exceptional for the 10-year period of our study.

Products from a surface ocean CO2 reference network, SOCONET

Richard Wanninkhof (AOML, NOAA, Miami, USA)

The nascent Surface Ocean CO2 NETwork (SOCONET) for measurement of CO2 from ships and buoys focuses on the operational aspects of measurements of CO2 in both the ocean surface and atmospheric marine boundary layers. The goal is to create a global network that provides accurate pCO2 data to within 2 micro atmosphere (μatm) for surface ocean and 0.2 parts per million (ppm) for marine boundary layer MBL measurements following rigorous best practices, calibration and intercomparison procedures. The network, will aid in production of important products such as maps of monthly resolved surface ocean CO2, and air-sea CO2 flux measurements. These products and other derivatives using surface ocean and MBL CO2 data, such as surface ocean pH maps will be of high value for policy assessments and socio-economic decisions regarding the role of the ocean in sequestering anthropogenic CO2, and how this uptake is impacting ocean health by ocean acidification. Here we will describe the effort and show an example on regional products in the Caribbean Sea that have been developed over the past two decades. These deliverables provide an idea of what can be delivered by the ICOS Ocean thematic Center.

Using SMOS soil moisture data combining CO2 flask samples to constrain carbon fluxes during 2010-2015 within a Carbon Cycle Data Assimilation System (CCDAS)

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The terrestrial carbon cycle is an important component of the global carbon budget due to its large gross exchange fluxes with the atmosphere and their sensitivity to climate change. Terrestrial biosphere models show large uncertainties in simulating carbon fluxes, which impact global carbon budget assessments. The land surface carbon cycle is tightly controlled by soil moisture through plant physiological processes. Accurate soil moisture observations thereby have the potential to improve the modeling of carbon fluxes in a model-data fusion framework. We employ the Carbon Cycle Data Assimilation System (CCDAS) to assimilate six years of surface soil moisture provided by the SMOS satellite in combination with global-scale observations of atmospheric CO2 concentrations. We find that assimilation of SMOS soil moisture exhibits better performance on soil hydrology modeling at both global and site-level than only assimilating atmospheric CO2 concentrations, and it improves the soil moisture simulation particularly in mid- to high-latitude regions where the plants suffer from water stress frequently. The optimized model also shows good agreements with inter-annual variability in simulated Net Primary Productivity (NEP) and Gross Primary Productivity (GPP) from an atmospheric inversion (Jena CarboScope) and the up-scaled eddy covariance flux product (FLUXNET-MTE), respectively. Correlation between SIF (Solar Induced Fluorescence) and optimized GPP also shows to be the highest when soil moisture and atmospheric CO2 are simultaneously assimilated. In general, CCDAS obtains smaller annual mean NEP values (1.8 PgC/yr) than the atmospheric inversion and an ensemble of Dynamic Global Vegetation Models (DGVMs), but larger GPP values (167.8 PgC/yr) than the up-scaled eddy covariance dataset (FLUXNET-MTE) and the MODIS based GPP product for the years 2010 to 2015. This study demonstrates the high potential of constraining simulations of the terrestrial biosphere carbon cycle on inter-annual time scales using long-term microwave observations of soil moisture.

Abstracts in ICOS National Networks and Thematic Centres showroom

To be updated as more are submitted

The first ICOS OTC pCO2 instrumentation inter-comparison

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In recent years, new technologies have been evolving with a whole new generation of sensors and instruments measuring the partial pressure of CO2 (pCO2) in both the ocean surface and sub-surface entering the market. These include upgraded versions of equilibrator-based systems with new CO2 detectors, as well as novel membrane-based sensors that can be submerged. In order to achieve a long-term homogeneity of the critical climate- and ocean health- relevant data based on these measurements, ICOS OTC in collaboration with the International Ocean Carbon Coordination Project, will organize a pCO2 instrumentation inter-comparison in June/July 2021 in Ostend, Belgium. This exercise will be open to the pCO2 community worldwide, aiming to achieve the following goals globally:

• to compare the performance of instruments and sensors that are (or will be) used within the ICOS community (and beyond) over a range of temperatures and pCO2 levels.

• to engage instrument suppliers and manufacturers to work together with the observational community to reach a higher level of standardization in operating pCO2 sensors and instruments.

• to provide objective information to the community highlighting essential, application-specific attributes to be considered when choosing the appropriate sensor.

The inter-comparison exercise will not only compare different instrumentation, but also provide insights on how to improve the handling of instrumentation and data in order to achieve the best possible measurement quality being delivered. All participants need to agree to make their data publicly available so that the outcome of this exercise can be widely communicated in a transparent way.

Here we present the outline of the inter-comparison and discuss the benefits for the ICOS and global marine CO2 community.

Abstracts in parallel sessions

Session 1: Urban observations and detection of human emission, part 1

Oral presentations in session 1

Improved understanding of urban street tree and soil carbon cycle

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Urban areas are responsible for a significant amount of carbon dioxide emissions, but fortunately several cities are striving to become carbon neutral. Achieving this will certainly require the reduction of emissions, but also carbon sequestration in order to meet the challenging targets. Urban carbon sequestration can be modelled using meteorological models that take into account the diverse urban structure. However, the impact of urban vegetation and soil on the carbon cycle is challenging to evaluate using measurements. Commonly used methods such as the eddy covariance method measure the net exchange of carbon dioxide between the earth and the atmosphere, leaving the effect of vegetation easily overshadowed by human emissions in urban areas. Therefore, this study focuses on the development and evaluation of carbon cycle models using measurements directly from urban street trees and soil.

In order to gain a better understanding of carbon sequestration in urban streets, both vegetation and soil need to be taken into account. For this reason, a stomatal control model is developed further to fit street trees in the urban land surface model SUEWS (the Surface Urban Energy and Water Balance Scheme) and, in addition, the soil carbon decomposition model Yasso15 is evaluated for the first time in urban areas. Both models are used to simulate urban carbon cycle on two streets in Helsinki, Finland for years 2003-2016. Curbside trees (Alnus glutinosa and Tilia x Vulgaris) were planted while the two test streets were constructed in 2002. Thereafter, carbon and water fluxes and pools with detailed street tree soil compositions were monitored in 2002-2014. Both photosynthesis and evaporation in SUEWS are based on stomatal conductance that depends on environmental factors. The stomatal conductance parameters for the model are fitted with sap flow and leaf-level photosynthesis measurements from the test trees. The modelled evaporation is evaluated against sap flow measurements to test the stomatal conductance model. Some of the measurements are used for both development and evaluation, however, in separate years. SUEWS creates a local spatially variable temperature and specific humidity environment which is used in the model runs. The Yasso15 model is evaluated against loss-on-ignition based soil carbon measurements as it has not been previously evaluated in urban soils. The modelled carbon dioxide flux combined with the changes in the soil carbon stock will be used to estimate the carbon cycle of urban street trees and soils.

Plume detection and characterization from XCO2 imagery: Evaluation of Gaussian methods for quantifying plant and city fluxes

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We have developed an algorithm for estimating CO2 emissions of power plants and cities from satellite images of the column averaged dry air carbon dioxide mixing ratio (XCO2). It uses an optimal estimation method (OEM) for fitting the measured images with a Gaussian plume model able to deal with multiple and/or extended sources like cities. The source emission is estimated by using adjusted Gaussian model parameters and wind profile information from Numerical Weather Prediction (NWP) fields. The approach properly considers uncertainties on all the plume model parameters, on a priori information on CO2 and on the wind profile, in order to provide a full analysis of the retrieval uncertainty and its dependence to OEM model hypotheses, source characteristics, atmospheric conditions, and observation specifications (spatial resolution and spatial coverage).

The method was evaluated against a set of atmospheric transport CO2 simulations over Western Europe that were generated based on kilometer scale emission inventories. These simulations were used to reproduce typical MicroCarb and GEOCarb synthetic images (with the presently known characteristics of these satellite CO2 sounders) over a representative number of European target sites covering power plants and cities in France, Belgium, Germany, Great-Britain and the Netherlands. The simulated observations have a realistic character and have been used in an OSSE like approach for assessing the potential of simulated satellite measurements for quantifying emissions and for estimating the performances of the flux retrieval method.

A comprehensive analysis of the expected precision on the source emissions, considering the impact of the configuration mode, of the complex behavior of the plume dynamics, and of realistic cloud coverage, is proposed.

In addition, we have used a set of Sentinel 5 Precursor NO2 images to evaluate the validity of the atmospheric transport model to reproduce column average images, and to assess the impact of the assumed wind profile (obtained from NWP centers).

Finally, we have used Large Eddy Simulation (LES) model to evaluate the impact of explicitly modelling atmospheric turbulence and of high spatial resolution on the transport of CO2 from point sources and on the resulting XCO2 images. In addition, we use LES results to estimate the uncertainties associated with the forward transport model in flux inversions studies.

These results are used to evaluate the potential of the specific City mode of the MicroCarb mission for quantifying CO2 emissions from space and for defining well-suited sites (power plants and cities) to be targeted by this measurement mode.Potential and complementarities of the GEOCarb configuration, and the impact of spatial resolution (pixel size) and coverage (area of the measurement scene), are also discussed.

Quantifying biogenic carbon dioxide fluxes in an urban area

Stavros Stagakis (Environmental Sciences, University of Basel, Basel, SWITZERLAND), Christian Feigenwinter (University of Basel, Basel, SWITZERLAND), Roland Vogt (University of Basel, Basel, SWITZERLAND), Miriam Mutti (University of Basel, Basel, SWITZERLAND), Etienne Zurbriggen (University of Basel, Basel, SWITZERLAND), Andrea Pitacco (University of Padova, Padova, ITALY)

Urban areas constitute complex and highly heterogeneous mosaics of CO_2 sources and sinks. Anthropogenic emissions - mainly from fuel combustion due to vehicle traffic, building heating, energy production and other industrial activities - are producing high amounts of CO_2, dominating the urban CO_2 flux. The biogenic fluxes (i.e. photosynthesis, autotrophic-heterotrophic respiration) are usually smaller than the anthropogenic fluxes in urban areas, however they potentially affect the seasonal and spatial variability of urban emissions according to green area cover fraction and seasonal climate variability. Quantifying the urban biogenic fluxes would help in discriminating human emissions from natural fluxes, recognizing the seasonal and interannual CO_2 emission variability and trends, enhance our current understanding on urban metabolism and function, and eventually improve the current urban emission inventories. Urban biogenic flux dynamics are expected to differ significantly from the rural ecosystems due to the extreme variability of urban climate in micro and local scales, urban-related stressors and diverse management practices. The Urban Heat Island (UHI) phenomenon is one of the factors that would potentially alter the urban biogenic CO_2 balance, since it affects both soil and air temperature which are important environmental drivers of the biogenic CO_2 flux processes. A relevant scientific question is if urban green tends to behave as carbon sink or source in the long term, which is still a matter of controversy in today's literature.

In the framework of diFUME project (https://mcr.unibas.ch/difume/), the spatial and temporal variability of CO_2 flux by the anthropogenic and biogenic sources and sinks in Basel city centre is modelled and monitored. The approach involves the development of mechanistic models of photosynthetic uptake, plant respiration and soil respiration, dedicated to urban environment, according to meteorological observations, spatial representation of urban structure and EO monitoring of vegetation dynamics. An extended urban sensor network in the study area is used to monitor air temperature, soil temperature and soil moisture variability. The spatial variability of solar radiation is modelled according to the 3-dimensional architecture of the urban canopy. A high-resolution aerial Lidar dataset of the study area is used to extract building and tree morphology, as well as tree Leaf Area Index (LAI). The multiple radiation interactions between buildings and urban vegetation are considered in a multilayer modelling approach of radiation intercepted by plant canopies, taking into account horizontal and vertical distribution of LAI and building structures. The biogenic flux models are calibrated during an extended field campaign of microscale in-situ CO_2 flux measurements on urban trees and soils of Basel city centre during the summer of 2020. This study presents the developed modelling approaches for the three biogenic fluxes, the first results from the field measurement campaign and initial estimations of the spatial and temporal variability the urban biogenic CO_2 fluxes.

In tandem optimisation of anthropogenic and biosphere CO_2 emissions using a simple fossil fuel emission model and C^{14}

Auke van der Woude (MAQ, Wageningen University, Wageningen, NETHERLANDS)

High-precision observations such as collected through ICOS, in combination with inversion systems, can potentially inform us on CO_2 fluxes on high spatial and temporal resolution. However, inversions often inform us only about the magnitude of the total carbon flux, but not the underlying split between natural and anthropogenic sources, nor the contribution of different processes or emission sectors. To address this challenge for fossil fuel emission monitoring, Super et al. (2020) created an inversion system that optimises parameters in a simple dynamic fossil fuel emission model, using measurements of CO_2, CO, NOx and SO_2 to disentangle the signature of different emission sources in the Rijnmond region. This enables us to better constrain emissions by different source sectors, and provides the possibility to monitor and validate emission reduction policies, that are often targeted at specific sectors. In our follow-up to Super et al's work with pseudo-data, we have now expanded the inversion system by (a) including Net Ecosystem Exchange fluxes and optimizable parameters, (b) adding radiocarbon (Δ14C) as an additional ICOS observational constraint on the carbon fluxes, and (c) expanding the domain of the system to cover a large part of Europe.

In this presentation, we will show first results from this expanded system, using both pseudo and actual data from the RINGO project, covering Germany, France, and the Netherlands.

Efficient sampling of atmospheric methane for radiocarbon analysis

Giulia Zazzeri (Physics, Imperial College London, London, UNITED KINGDOM) Xiaomei Xu (Physics, University of California, Irvine, Irvine (CA), USA), Heather Graven (Imperial College London, London, UNITED KINGDOM)

Atmospheric methane observations have shown a dramatic increase in methane concentrations over the past ten years (Nisbet et al. 2019). The contribution to this rapid growth remains poorly understood, showing a need for better identification of methane sources. Radiocarbon is one of the most powerful tracers for distinguishing fossil from biogenic sources on global and regional scales (Lassey et al. 2007; Graven et al. 2019). Fossil methane has lost all its ^{14}C over millions of year of radioactive decay and, when emitted to the atmosphere, causes a strong decrease in the ratio of radiocarbon to total carbon in methane ($\Delta^{14}CH_4$). By observing changes in $\Delta^{14}CH_4$, the fossil fraction of methane emissions can be quantified. Despite their usefulness, presently there are very few published measurements. This is mainly due to challenges in the sampling procedure.

In this study we present the development of a unique sampling system for $^{14}CH_4$ analysis that enables efficient collection of enough carbon for high precision $\Delta^{14}C$ measurements. Our sampling procedure is based on the use of molecular sieve (zeolite), and it separates the methane carbon from air during sampling, reducing the need for sample processing at the radiocarbon laboratory and associated costs.

We use the system to produce the first $\Delta^{14}CH_4$ measurements in central London, showing that day-to-day differences in $\Delta^{14}CH_4$ in these samples can be attributed to fossil methane.

Poster presentations in session 1

Development of a long-term environmental research infrastructure in South Africa

Gregor Feig (EFTEON, SAEON, Tshwane, SOUTH AFRICA), Kerneels Jaars (EFTEON, SAEON, Tshwane, SOUTH AFRICA)

South Africa is developing a long term Environmental Research infrastructure under the South African Research Infrastructure Roadmap (SARIR) program of the Department of Science and Innovation (DSI). The Expanded Freshwater and Terrestrial Environmental Observation Network (EFTEON) is being developed as a modular research infrastructure to support studies on coupled ecological social systems in South Africa. The design concept is based on developing 6 research "Landscapes" each with responsibility for a core sites representing an important South African Ecosystem/Human complex. The Landscapes are intended to include representatives of major biomes in South Africa and human transformed ecosystems. Each of the landscapes will have a standard set of automated instruments, measuring the carbon and water cycles and, meteorology and air quality. A suite of standard repeated manual measurements, covering biodiversity, productivity, ecosystem condition, ecosystem service provision and use. Automated instrumentation for the measurement of water quality and supply will be deployed in each landscape. A larger set of subsidiary sites associated with each landscape will have simpler standard automated instruments for climate and fresh water monitoring and repeated manual measurements, including household survey data collection in surrounding communities. The products envisaged from EFTEON include: 1) half hourly fluxes of energy, carbon dioxide and water for a representative site within the landscape, accompanied by continuous measurements of meteorology, soil moisture, soil temperature and periodic documentation of vegetation, soil and disturbance parameters. 2) The hydrological system in the landscape, river flow, daily groundwater recharge, continuous stream chemistry, 3) Landscape scale observations of land use and land cover including human population, livelihoods, health and use of resources, inputs and disturbances, 4) Population dynamics of representative and important species in the landscape for both terrestrial and freshwater ecosystems. This presentation will highlight the development of the EFTEON RI, the process for engaging with the research community and the landscape selection process.

Towards ICOS labelling of urban sites - review of ICOS protocols from an urban perspective

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ICOS RI is about to involve urban stations into the monitoring program. The first urban stations are already labelled as associated site. The ETC Working Group „Measurements over Urban Areas“, established in 2018, aims to define standard methods for fluxes and meteorological measurements over urban areas. A „Workshop on strategies to monitor greenhouse gases in urban environments“ organized by this Working Group in Helsinki/Hyytiälä from July 1-4 in 2019 in order to discuss the topic. Among others, it was agreed, that the ICOS protocols and labelling criteria for natural ecosystems have to be adapted to the specific properties of urban flux towers, if it comes to a labelling process for urban sites within ICOS RI. This contribution reviews the ICOS protocols as published in Int. Agrophys. 2018, 32 and the labeling criteria for ICOS ETC class 1 and class 2 sites from an urban perspective and lists possible modifications to be implemented in a future labelling process for urban sites.

Evaluating the performance of a Picarro G2207-i O_2 analyser in real-world applications

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Fluxes of O_2 and CO_2 in and out of the atmosphere are strongly coupled for terrestrial biospheric exchange and fossil fuel combustion but are uncoupled for oceanic air-sea gas exchange. High-precision measurements of atmospheric O_2 can therefore provide additional constraints on the carbon cycle and can be used to verify fossil fuel CO_2 ($ffCO_2$) emission estimates. However, due to the large atmospheric background mole fraction of O_2 (~20.95%) it is very challenging to measure small variations in atmospheric O_2 to the degree of precision and accuracy required for these applications, since measuring a change of 1 ppm of O_2 against this background requires a precision of 0.0005%. Existing O_2 analysers which meet this measurement challenge are complex systems to build and maintain; therefore, an alternative ""off-the-shelf"" O_2 analyser could revolutionise the field of atmospheric O_2 measurements, if the required performance could be achieved and if it were relatively easy to operate with low maintenance requirements.

We have tested an atmospheric O_2 analyser based on the principal of cavity ring-down spectroscopy (Picarro Inc., G2207-i), both in the laboratory and at the Weybourne Atmospheric Observatory field station in the UK, in comparison to a well-established, pre-existing in situ atmospheric O_2 and CO_2 measurement system. The precision, accuracy, and performance of the Picarro analyser have been evaluated with full, partial, and no drying of the sampled air. The instrument drift and the frequency at which a tailor-made optimised calibration protocol needs to be run have also been investigated.

In order to further examine the Picarro analyser's performance in real-world applications, we have also calculated results of $ffCO_2$ from Weybourne using Picarro O_2 data and compared this to $ffCO_2$ estimates calculated from the pre-existing measurement system.

Quantifying CH_4 coal mine emissions in Upper Silesia by passive airborne remote sensing observations during CoMet

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Methane (CH_4) is, after carbon dioxide (CO_2), the second most important anthropogenic greenhouse gas in our atmosphere. However, reliably estimating CH_4 emissions, as emitted by coal mining, is still a major challenge. In May and June 2018, the CoMet campaign was executed attempting to measure and subsequently quantify emissions of one of the largest CH_4 emitting areas in Europe, the Upper Silesian Coal Basin (USCB, Poland), starting from single shafts over smaller clusters up to the entire basin. Methane emissions from that area reach around 500 ktCH_4/yr from various mining shafts distributed over around 50 x 50 km^2. During the campaign various platforms (aircraft, car, stationary) and instruments (active and passive remote sensing, in-situ, wind lidar, FTIR) were deployed to achieve that goal.

Here, we will focus on the data set acquired by the passive airborne remote sensing instrument MAMAP (Methane Airborne MAPper), which uses absorption spectroscopy to infer atmospheric CH_4 concentration gradients. These gradients were combined in a simple mass balance approach with wind information from three wind lidar stations deployed in USCB to infer cross-sectional CH_4 fluxes through different flight tracks located downwind of various mining shafts. The computed fluxes could eventually be assigned to specific mining shafts, or small clusters of mining shafts, and compared to reported CH_4 emissions.

Averaged observed fluxes range from ~7 to 80 ktCH_4/yr for single clusters derived from multiple overflights on different days. Associated uncertainties are in the range of 15% to 45% of the respective fluxes and largely depend on the number of available flight tracks and atmospheric conditions, e.g. prevailing wind speed. In total around 20 shafts were investigated corresponding to around 40% of the total CH_4 mining emission in that area. A comparison to reported values revealed good agreement within the uncertainty of the observations.

Mobile measurement of carbon dioxide and methane emissions in Cyprus

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The Mediterranean is highly sensitive to climate change. The region remains a minor contributor to greenhouse gas (GHG) emissions. Cyprus is an island located in the eastern part of the Mediterranean Sea. It represents a potential useful observatory of regional emissions with upstream air masses transported from Europe, Asia, and Africa, as well as to local anthropogenic emissions. Distributions in this region remain challenging to assess and characterize mostly because of a lack of atmospheric measurements. This study presents the first mobile collection of atmospheric carbon dioxide and methane measurements in this island, aiming to obtain a comprehensive understanding of the GHG distributions and emissions. The data and results will allow validation of emission inventories, identification, and quantification of poorly-known GHG sources.

The spatially resolved horizontal and vertical observations of this study are conducted using cars and unmanned aerial vehicles (UAVs). The ground-car-based observations are based on a Picarro (G2401) set-up that measures simultaneously atmospheric carbon dioxide (CO2), methane (CH4), carbon monoxide (CO), and water vapor (H2O) to characterize GHG hotspots in Cyprus.

For the airborne measurement, validated UAV-GHG sensor systems are used to map specific source emissions close to the ground. The sensors used here are based on the SenseAir AB CO2 High-Performance Platform. The CO2 sensors accuracy and linearity tests were performed in the laboratory. Allan Deviation showed that the sensor precision lies within ±1ppm (1σ) at 1 Hz. Corrections due to temperature and pressure changes were performed using specific formulas obtained from chamber experiments. Additionally, manned aircraft tests were performed, to evaluate the adequacy of the P/T correction equations for the two CO2 sensors. The results were compared against an airborne reference instrument (Picarro G2401-m). Following the above laboratory and airborne tests, the HPP CO2 sensor was integrated into a small fixed-wing UAV with a wingspan of 1.83m, and customized avionics and payload developed by the Unmanned Systems Research Laboratory of the Cyprus Institute (USRL). The integrated system performed successful atmospheric profiling within the boundary layer, at an agricultural site in Cyprus. The same HPP CO2 sensor is planned to be integrated into a quad-copter that allows vertical take-off and landing (VTOL) in urban environments. These mobile measurements provide us with useful insights into CO2 hotspot emissions close to the ground for different (remote/urban) regions in Cyprus.

Tests and Implementation of a Dense-Network Urban PM2.5 Inversion System

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PM2.5 emissions, which have been linked to a host of respiratory conditions and other negative human health effects, continue to increase as urbanization increases. Because of their immediate health impacts, policymakers and officials around urban centers could greatly benefit from having accurate, up-to-date assessments of the local emission conditions. The Mapping Air Pollution eMissions (MAPM) project uses Christchurch, New Zealand as a testbed for a very-high-measurement-density urban PM2.5 inversion system. During a measurement campaign in the summer of 2019, there were 60 well-functioning measurement instruments, including 11 colocated instruments, blanketing and surrounding the urban area. This observation network is used in combination with high-resolution atmospheric transport modeling to establish a Bayesian-based inverse modeling system, in order to provide the most accurate emissions maps possible. Observation System Simulation Experiments (OSSEs) show the abilities and limitations of this system, and real-data inversions using the actual measurements show the hot spots and weak spots in the domain post-simulation.

A Dual Frequency Comb spectrometer suited for open-path greenhouse gas and trace gas detection

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Understanding human contributions to the budget of greenhouse gases as well as identifying and understanding natural sources and sinks will be crucial for the future of humankind. For that, two approaches are often pursued. First, determining deviations from typical atmospheric concentrations combined with wind direction and flux as done for leakage detection of methane, and second, investigating isotope ratios as $\delta^{13}C$ of CO_2 or CH_4 from different sites and times. Both strategies require the detection of low gas concentrations with high accuracy and precision. Most systems employed suffer from either low sensitivity or a restricted to laboratory environments.

We present a high-resolution spectrometer capable to record low noise transmission spectra of air detecting either CH_4 at 3.3 µm or N_2O and CO_2 at 4.48 µm. The system utilizes the technique of dual-comb spectroscopy for which we generate two combs at 1.55 µm by intensity modulation of a single cw-laser. This simplifies data acquisition and processing which reduces the complexity of the system significantly. The combs are converted to the MIR by difference frequency generation for which an optical-parametric oscillator tunable from 1.0 µm to 1.2 µm generates the pump light. Hence, the converted combs can be positioned within the MIR over the full range from 3 µm to 5 µm. The spectral coverage of a single spectrum is up to 800 GHz, which allows investigating multiple absorption features of a sample at once. The MIR dual-comb is split into two branches where one serves as reference channel to account for the complex comb envelope structure. The other propagates through a multi-reflection cell with 7.2 m of total absorption length. With this configuration we compare spectra of N_2 serving as reference spectrum with an arbitrary sample – here air at 0.98 atm. A fit to a spectrum recorded at 3.3 µm utilizing the HITRAN database results in 2.05(3) ppm CH_4 in the presence of 6.53(5) % H_2O. 327(2) ppb N_2O and 415.9(1.7) ppm CO_2 are derived from a spectrum recorded at 4.48 µm. Optical interferences dominate the residuals but are typically two orders of magnitude weaker than the absorptions features. The RMS-noise is at even lower levels for 10 s measurement time per spectrum.

With the current high pulse powers (up to 1 W) of the MIR dual-combs and a beam profile close to the TEM_{00} mode the usage of a long-path cell exceeding 100 m or open-path measurements over kilometers become feasible, targeting sensitivities sufficient to determine isotope ratios or to detect small changes of concentrations. This – combined with the potential of the reduced complexity of the system - shall result in a field-deployable device and allow new opportunities for atmospheric monitoring with high accuracy and precision while still being fast enough to track dynamics occurring on sub-minute time scales.

Performance of low-cost metal oxide sensors in the reconstruction of CH_4 observations at background levels and at artificial high levels generated in laboratory.

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The deployment of a dense network of high precision analysers to detect or estimate CH_4 emissions in the vicinity of industrial sites is costly. Employing low-cost sensors to sample continuous CH_4 emissions becomes an interesting alternative, even considering their limitations like a lower sensitivity to CH_4 concentration, cross-sensitivity to other species and drifts over time. Figaro TGS metal oxide sensors were employed on this study; their functioning is based on measured variations of resistance affected by electron donors in the air in which the target species is present. We have conducted our study on two datasets of continuous measurements, the first dataset consisting of 3 months of room air observations and the second dataset of 5 months of ambient air observations where artificial spikes were generated over the background signal variations, with concentrations varying from 3 ppm to more than 24 ppm and for durations going from 15 seconds to several minutes. In addition, for both datasets other ambient variables were also measured such as pressure, temperature and water vapour mole fraction.

We have used a machine learning model, a Multilayer perceptron, to reconstruct CH_4 concentrations from resistance measurements from the low-cost sensor on the first dataset. Obtaining an error RMSE < 0.2 ppm at an hourly scale. In addition, several tests were conducted to determine the sensitivity of the model to the input variables. We have observed that water vapour mole fraction has the strongest effect on the model. For the second dataset, an automated algorithm to detect the artificial spikes was employed to detect and remove the background signal to compare the response of the Figaro TGS sensors to high variations of CH_4 concentrations. A linear model was applied to observe the correlation with a high precision instrument obtaining an $R^2 > 0.9$. Then a multilinear model was trained with the Figaro TGS resistance and the other ambient variables as an input obtaining an RMSE of 0.21 ppm.

Finally, on both experiences we have observed the potential of Figaro TGS sensors to measure the variability of CH_4 mixing ratios at background levels as well at higher levels obtaining good correlations and a low RMSE.

Uncertainties in a high-resolution gridded emission map and the importance for urban scale emission verification

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Urban areas are an important contributor to the total fossil fuel greenhouse gas emissions and are increasingly targeted by emission reduction policies. This requires accurate localisation of emission sources as well as independent verification of the emissions at a high spatial and temporal resolution, for example through inverse modelling. One main challenge in urban-scale inverse modelling is that the quantification of uncertainties in the prior emissions is often lacking and the effect of spatiotemporal downscaling is not well-understood. We have analysed the uncertainties in a gridded high-resolution (1x1 km², 1 hour) emission map for the greenhouse gases CO_2 and CH_4, but also for co-emitted species CO and NOx. A Monte Carlo simulation was done using the (reported and/or estimated) uncertainties in the underlying data, including the proxies used for spatial and temporal downscaling. We show sectoral emission uncertainties for the Rotterdam area in the Netherlands and demonstrate that the assumption on the spatial distribution of minor point sources can cause a difference of up to 3.5 ppm in the simulated CO_2 concentration at an urban observation site. Moreover, we show that a spatial map of uncertainties can support the design of an observation network that is optimized for constraining fluxes with the largest uncertainties. Finally, the uncertainty data is used in a one-week inversion to examine the importance of a correct representation of the error covariances. With this approach we were able to attribute a bias in the CH_4 concentration to a shortcoming in the CH_4 emission timing, which has now been improved and included in new releases of the emission data.

Session 2: Impact of COVID-19 lockdown on anthropogenic emissions

Oral presentations in session 2

COVID-19 causes record decline in global CO2 emissions

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The unprecedented cessation of human activities during the COVID-19 pandemic has affected global energy use and CO2 emissions. Here we show that the decrease in global fossil CO2 emissions during the first quarter of 2020 was of 5.8% (542 Mt CO2 with a 20% 1-σ uncertainty). Unlike other emerging estimates1, ours show the temporal dynamics of emissions based on actual emissions data from power generation (for 29 countries) and industry (for 73 countries), on near real time activity data for road transportation (for 132 countries), aviation and maritime transportation, and on heating degree days for commercial and residential sectors emissions (for 206 countries). These dynamic estimates cover all of the human induced CO2 emissions from fossil fuel combustion and cement production. The largest share of COVID-related decreases in emissions are due to decreases in industry (157.9 Mt CO2, -7.1% compared to 2019), followed by road transportation (145.7 Mt CO2, -8.3%), power generation (131.6 Mt CO2, -3.8%), residential (47.8 Mt CO2, -3.6%), fishing and maritime transport (35.5Mt CO2, -13.3%) and aviation (33.4 Mt CO2, -8.0%). Regionally, decreases in emissions from China were the largest and earliest (-10.3%), followed by Europe (EU-27 & UK) (-4.3%) and the U.S. (-4.2%). Relative decreases of regional CO2 emissions are consistent with regional nitrogen oxides concentrations observed by satellites and ground-based networks. Despite the unprecedented decreases in CO2 emissions and comparable decreases in economic activities, we monitored decreases in the carbon intensity (Emission per unit of GDP) in China (3.5%), the U.S. (4.5%) and Europe (5.4%) over the first quarter, suggesting that carbon-intensive activities have been disproportionally impacted.

Observation of urban CO_2 emissions using spatially dense low-cost sensing and modelling

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The interest in dense CO_2 measurement networks is growing, especially in urban areas. This closely relates to the need for tools to monitor the success of policies, implemented by cities and communities, for the reduction of greenhouse gas emissions. Within this context, we setup Carbosense, a dense, Swiss CO_2 sensor network. It consists of 250 nodes and has a focus on the city of Zurich, where more than 50 sensors are deployed. The network includes three types of measurement units: (i) 3 high-precision laser spectrometers (Picarro G1301/G2302/G2401), (ii) 15 temperature stabilized, mains powered NDIR low-cost instru-ments with reference gas supply (SenseAir HPP), and (iii) 250 nodes of battery-powered NDIR low-cost sensors (SenseAir LP8). LP8 and HPP sensor data is transmitted using a low-power IOT network (LoraWAN, Swisscom). The Carbosense network is operational since July 2017.

Each of the LP8 and HPP sensors are individually calibrated in pressure and climate chambers, and by field measurements with co-located reference instruments. Especially LP8 sensors are susceptible to environmental conditions, such as relative humidity, and their response drifts over time. To account for this, an elaborate, operational system for data acquisition and data treatment was developed, which provides near real-time, calibrated CO_2 data with a time resolution of 10 minutes. The accuracy of the HPP and LP8 sensors is about 2 ppm and 10 ppm, respectively. The data yield for the LP8 sensors is about 70 %, while the availability of the HPP and Picarro measurements is > 95 %.

An extensive data record is now available and exploited in various ways. Some key results are as follows: (i) drift correction of LP8 is a critical parameter to obtain reliable results. A correction based on strong wind conditions, and thus a flat CO_2 concentration distribution, proved to be efficient. More elaborate strategies involving the comparison of the measurements with modelled concentrations is currently being evaluated. (ii) The CO_2 measurements are generally in good agreement with results obtained using emission estimates and an atmospheric transport model (COSMO-GHG). However, frequent underestimation of modelled CO_2 con-centration during nighttime, when CO2 is accumulating in a shallow planetary boundary layer (PBL), indicate an overestimation of the modelled PBL height. The sensor data may prove to be useful to evaluate and optimize the respective model processes and parameters. (iii) The sensor data together with geographic information is well suited for spatially resolved statistical models. (iv) CO_2 sensor measurements in the city of Zurich clearly show the impact of traffic, concurring with co-located measurements of NO and NO2. (v) Sensor measurements before and after the Covid-19 lockdown, combined with predictive modelling, reflect the impact of the Covid-19 measures on the urban CO_2 concentration distribution, especially near streets with high traffic.

The evaluation of these measurements, and concurrent improvements in measurement strategies, data treatment and modelling is ongoing. Ultimately, we target accurate near real-time CO_2 maps with high spatio-temporal resolution, and an enhanced tracking of urban CO_2 sources.

Comparison of atmospheric CO, CO_2 and CH_4 measurements at Schneefernerhaus and the mountain ridge at Zugspitze, Germany

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Since 2002 the mole fraction of CO_2, CH_4 and CO are measured at the Environmental Research Station Zugspitze-Schneefernerhaus (ZSF), Germany. Especially the CO and also the CO_2 record measured at ZSF are occasionally influenced by local pollutants. Particularly in winter, snow groomer and gasoline snow blowers leads to strong CO peak.

To study the effect of local pollution events, and to examine the flagging of these data, a 290 m stainless steel tube, sheltered inside a reinforced stainless steel tube, was installed to sample ambient air from the mountain ridge uphill of the ZSF. Since October 2018 ambient air, pumped from the mountain ridge is measured for CO_2, CH_4 and CO with an additional Cavity-Ring-Down Spectroscopy (CRDS) analyser at ZSF.

Measurements sampled at the mountain ridge show similar large scale patterns, but as expected, much less influence of local pollution compared to ZSF. Between October 2018 and May 2020, 2261 CO_2 and 997 CO pollution events were flagged manually in the ZSF time series. At only 18% of the days when those high CO_2 or CO events are noticed at ZSF corresponding peaks in the mountain ridge measurements are clearly visible. Even high CO events of up to 28 000 ppb measured at ZSF due to the usage of gasoline snow blowers at ZSF are most of the time not visible in air collected at the mountain ridge. Local pollutions could only be seen at both measurement sites especially when the wind blows from south-east.

Although the local wind patterns are quite different for both locations, due to the shape of the mountain, the mole fraction of CO, CO_2 and CH_4 from ambient air at ZSF and at the mountain ridge are comparable with a mean difference between the dried measurements of 1.7±3.3 ppb for CO, -0.4±4.2 ppb for CH_4 and 0.1±0.5 ppm for CO_2.

Since mid-March, the tourism operations at Zugspitze have been suspended due to COVID-19 pandemic and also work at ZSF was reduced. However, as the measurements kept running this gives us the unique opportunity to analyse the impact of tourism and the operation of ZSF on the measurements from another perspective.

This study demonstrates clearly, that ambient air at the mountain ridge is less influenced by local pollution. However, the inlet line on the mountain ridge is not always accessible for maintenance, which can introduce data gaps. Therefore, the continued measurement of ambient air from both locations (ZSF and mountain ridge) will be valuable for a complete picture.

Inter-annual variability of Eddy Covariance CO_2 flux measurements in the city center of Heraklion, Greece

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Understanding the interactions between urban CO_2 emissions with urban form and function and establishing city-scale emission inventories to account cities' contribution to climate change, are current challenges for the global scientific community. The Eddy Covariance (EC) method can provide in-situ measurements of energy and CO_2 fluxes (Fc) between a surface source area (local scale) and the atmosphere, proving to be an auspicious approach for quantifying CO_2 budget of urban areas. The center of Heraklion is an interesting study area in the global network of urban EC stations due to the complex urban morphology, the Mediterranean climate and the mixture between residential neighborhoods and busy commercial zone. A tower-based EC system is active for a three-year period over the city center of Heraklion. Fc was calculated for this period at 30-min time step and the time-series were quality-controlled and gap-filled using a moving look-up table (mLUT) technique. Gap-filled time-series were then temporally aggregated to monthly and yearly emission totals. Furthermore, the annual flux source area was estimated using the Flux Footprint Prediction (FFP) model, parameterized using urban morphological parameters extracted from a Digital Surface Model. To examine the directionality of the observed fluxes, the annual Fc has been additionally estimated by dividing the source into four wind direction sectors. The diurnal patterns per sector showed significant differences, especially the ones coming from the source area that characterize the commercial zone of the city center. The latter present considerably higher Fc than the sectors related to the residential zones. The inter-annual Fc variability per sector reflects the changes in the traffic patterns in the commercial area and the residential heating contribution during winter in the residential area which is related to winter temperature. Finally, the CO_2 fluxes during the government measures for COVID-19, in March and April of 2020 are presenting an important reduction in Heraklion case study that reflects the total lockdown of the commercial and traffic activities in the city center.

Pollution events, heatwaves, COVID lockdowns: what do we see in our recent atmospheric CO2, CH4, N2O observations in France?

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Since the installation of the first continuous CO2 analyser in France, at Puy de dôme in 2000, the greenhouse gases monitoring network has been significantly developed with the objective to characterize regional signals and their relation with surface emissions. Some surface sites have integrated ICOS-ERIC, and two stations are measuring total columns as part of TCCON. Other sites have been developed in France as part of research projects, focusing for example on the Ile de France region. In this presentation we will analyse the variabilities of CO2, CH4 and N2O observed over the past 5 years. Depending on their environment, the stations are more or less influenced by local emissions or large-scale processes. We will present few results illustrating the use of the atmospheric time series at different spatial and temporal scales, like very short-term variations used as an indicator of local emissions, or the frequency and intensity of pollution events passing over France, and the perturbation of the seasonal cycles associated with heatwave. We will also make a focus on the most recent observations to evaluate the signal due to the lockdown period in March-April 2020, at background and urban sites. Implications on the measurement precisions will be discussed.

Poster presentations in session 2

Greenhouse gases measurements at the urban environment of Athens, Greece

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The atmosphere is the layer of gases, particles and clouds surrounding our globe, receiving each year billion of tons of pollutants. Major sources of this pollution include fossil fuel combustion, cooking with solid fuels and wildfires. The ultimate by-product of all forms of burning is the emission of carbon dioxide (CO2), which, along with carbon monoxide (CO), methane (CH4) and water vapor (H2O), constitute the primary greenhouse gases (GHGs). GHGs trap the long wave radiation given off by the planet, causing thus a raise in ambient temperature. First CO2 measurements back in 1958 were merely 316 ppb, while nowadays we are well past 400 ppb. This study presents the first long-term GHGs observations in the urban environment of Athens. CO2 and CH4 present a clear annual cycle with maximum values during winter and minimum during summer. Maximum values for CO2 during winter sometime exceed 600 ppm, with an annual average of 425±28 while CH4 has an annual average of 2020±121 ppb. Levels of other major cities such as Paris and Mexico City are compared, as also background values at Finokalia, Crete. The comparison of Athens measurements with those conducted at Finokalia, a regional background location for the eastern Mediterranean, allowed to estimate urban emissions on a seasonal basis. A clear seasonality is seen on CO2 with minimum in summer and maximum in winter, while for CH4 not such seasonality is observed. The ratio of CO/CO2 is derived on a seasonal basis and finally, bivariate (wind speed-direction) polar plots in addition to hysplit are used to decipher possibly point sources. The impact of lockdown due to COVID-19 on urban emissions of greenhouse gases will be also presented.

Influence of SARS-CoV-2 lockdown on atmospheric background CO_2 values measured at the High Altitude Research Station Jungfraujoch, Switzerland

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The SARS-CoV-2 pandemic caused a lot of turmoil around the world and many governments asked their people to stay home or ordered partial or even complete lockdowns. Hence work traffic and recreational traffic are reduced, most air traffic has been canceled, and industry lowered their working hours and cut back production. However, the influence of this partial short-term reduction of carbon dioxide (CO_2) emission on the global background CO_2 mole fraction is most probably minor, since CO_2 emissions are reduced only partially over a limited period of time.

To detect deviations from normal caused by special events, such as the SARS-CoV-2 pandemic, well-characterized stations with long records are needed. Such a station is the High-Altitude Research Station Jungfraujoch, Switzerland. Since the end of 2004, the Climate and Environmental Physics Division of the Physics Institute, University Bern (Switzerland) has continuously been measuring CO_2 and oxygen (O_2) mole fractions of atmospheric air at Jungfraujoch. Due to its altitude of 3580 m a.s.l., Jungfraujoch predominantly receives air masses from the free troposphere that are considered to mostly represent background air with a footprint covering the complete Central European area. The preceding 14 years of CO_2 measurements until spring 2019 provide an excellent basis for characterizing usual CO_2 variations and for detecting potential changes in atmospheric background CO_2, if any, caused by the emission reduction due to the measures taken to contain SARS-CoV-2. Results of the analysis on this high altitude record will be compared to the urban station at Bern city, Switzerland including an analysis about changing CO_2 increase rates and carbon oxidation ratios ($\Delta O_2/\Delta CO_2$).

Assessing the impact of the Spring 2020 COVID-19 lockdown on atmospheric CO2 concentration in the Aix-Marseille area, France.

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In France, the COVID-19 lockdown was implemented on March 17th, 2020 and started to be partially lifted on May 11th, 2020. This lockdown strongly impacted the social and economical activities in the whole country. In this study, we will assess the impact of the lockdown on atmospheric CO2 concentration in the Aix-Marseille area. This area, located in the south-east of France, represents the second most populated area of France (1.8 M inhabitants). The analysis of CO2 continuous timeseries collected at the following three sites will be presented : the ICOS-Atmosphere OHP station (Observatoire de Haute Provence), located 100 km north of Marseille city and the Mediterranean coast ; the ICOS-Ecosystem station (Fontblanche), located 30 km east of Marseille ; and the Marseille Longchamps station, located in the heart of Marseille city. Correlations of atmospheric CO2 with tracers such as CO, NOX and black carbon will be analysed to detect the influence of anthropogenic emissions vs biospheric ones on atmospheric CO2 in the area, especially from the traffic and wood burning sectors. Some initial conclusions for conducting future CO2 emissions mitigation efforts in the Aix-Marseille region will be outlined from this specific case study.

Session 3: Innovation and uncertainty in observation techniques, part 1

Oral presentations in session 3

Assessing decoupling of above and below canopy air masses and its biasing influence on EC derived forest carbon budgets at a Norway spruce stand in complex terrain

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Concurrent below (0.14 • canopy height) and above canopy sonic anemometer vertical velocity (w) measurements reveal frequent decoupling events between the air masses below and above the canopy at a dense spruce forest stand in mountainous terrain. Decoupling events occurred predominantly during nighttime but not exclusively. Several single-level approaches based on steady state and integral turbulence characteristic tests as well as u* filtering and two-level CO_2 flux filtering methods are tested.

These tests aimed at evaluating the filtering schemes to address decoupling and its biasing effect on above canopy derived eddy covariance CO_2 fluxes. In addition to the already existing two-level filtering approach based on the correlation of σ(w) above and below canopy, two new filtering methods are introduced based on w raw data below and above the canopy. One is a telegraphic approximation agreement, which assumes coupling when w both above and below canopy are pointing in the same direction. Another one evaluates the cross correlation maximum between below and above canopy w data. This study suggests that none of the single-level approaches can detect decoupling when compared to two-level filtering approaches. It further suggests that the newly introduced two-level approaches based on w raw data may have advantages in comparison to the conventional σ(w) approach regarding their flexibility on shorter time scales than one year. We tested the correlation of the newly introduced filtering approaches with the parameters u*, global radiation, buoyancy forcing across the canopy and wind shear across the canopy. In any case, this correlation was not existing or weakly positive, suggesting that concurrent below and above canopy measurements are mandatory for addressing decoupling sufficiently. Sonic anemometer measurements near the forest floor and above the canopy are sufficient to apply the new procedures and can be implemented in a routine manner. Such a setup has a large potential to improve the uncertainties in EC derived forest carbon budgets in measurement networks like ICOS and at any forest site globally.

Reconstructing sub-surface Dissolved Inorganic Carbon from observations in the Southern Ocean

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The Southern Ocean carbon sink is highly variable. However, it is unclear how this variability is reflected in the dissolved inorganic carbon (DIC) pool, and the drivers behind this variability are still debated. Here, we use repeat hydrography measurements of DIC from the GLODAPv2.2019 database in combination with a 2-step mapping approach to obtain monthly global fields of interior DIC from 2004 through 2017 to investigate the interannual signal until 500 m depth in the Southern Ocean south of 35°S. At the sea surface, the strongest signal is the anthropogenically-forced DIC trend with little variations resulting from reduced sub-surface DIC transport. Our results further suggest a pronounced sub-surface DIC reduction from 2004 through 2009, followed by a strong recovery until 2012. This reduction is most prominent south of the Polar Front and extends to 500 m. The timing of these sub-surface variations is in line with proposed variations in the meridional overturning circulation.

Vertical gradients of greenhouse gases at 8 German atmospheric ICOS Stations

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The German Meteorological Service (DWD) runs eight ICOS Atmospheric tall tower stations across Germany since 2015. At each station concentrations of carbon dioxide (CO_2), methane (CH_4), carbon monoxide (CO) and nitrous oxide (N_2O) as well as meteorological parameters are continuously observed at 3 to 5 measurement heights (up to 341 m a.g.l.). Currently, modellers use only the top height measurements in their studies, but the gradient measurements provide a wealth of more information that can be utilised e.g. for characterizing the spatial representativeness of the GHG measurements.

Vertical gradients of these species are compared in terms of time (seasonal/diurnal) and space (tall tower station / mountain station) and statistics about the magnitude and frequency of these gradients are shown. We also investigate how the gradients compare to the overall measurement uncertainty. Using a footprint model we compare the spatial representativeness of the measurements with different gradients. Furthermore, we show how the vertical gradients can be used for data quality control by comparing the measurements of the different heights under well-mixed conditions. Under such well-mixed conditions there should be no marked differences between the concentrations at different heights and a leakage in one of the sampling lines could be seen.

Vertical gradients contain valuable information for spatial representativeness and can be a useful tool for quality control at atmospheric tall tower stations.

ICOS flask sampler performance tests

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At ICOS class 1 atmospheric monitoring stations, flasks are filled in regular intervals with ambient air using an automated flask sampler. The ICOS flask sampler usually comes with 24 ports that can be equipped with flasks of different sizes, sampling times as well as filling methods and duration can be preprogrammed. The flask samples are not only used to measure gas species (e.g. SF_6) and isotopic ratios (e.g. $\Delta^{14}C$) that are not measured in-situ but also for quality control of the in-situ measurements. In any case, it has to be ensured that the flask sampler does not fractionate the sampled air, no matter which sample method or port is used.

To test this prerequisite, a series of experiments were performed with the flask sampler of ICOS-CH consortium at the Climate and Environmental Physics Division, Physics Institute, University of Bern (Switzerland), dedicated to the ICOS class 1 atmospheric monitoring station at the High Altitude Research Station Jungfraujoch. The individual ports were tested by filling 2-liter flasks at each port using the constant flow method. The sampled gas was delivered by a high pressure cylinder with known gas composition. The flask sampler offers also a 1/t-method, in which the gas flow decreases as a inverse function of time. The advantage of this sampling method is that every point of time is equally represented in the sample, while with the constant flow method the gas sampled at the end is overrepresented compared to gas sampled at the beginning. However, the 1/t-method might be prone to fractionation, because already from the beginning of the sampling, the gas flow is split in a high waste flow and smaller sample flow and this ratio gets even more pronounced the longer the sampling lasts. To test for potential fractionation, six 2-liter flasks were sampled for 15 minutes and two 2-liter flasks were sampled for one hour using the same high pressure cylinder as in the previous experiments. After the sampling, CO_2 as well as $\delta O_2/N_2$ and $\delta Ar/N_2$ were measured by mass spectrometry and compared to the assigned values of the high pressure cylinder. The measurements show that all 24 ports as well as the different sampling methods yield the same results, which match the assigned values of the cylinder within the measurement uncertainty and that the flask sampler performs well under laboratory conditions.

Uncertainty analysis for calculations of the marine carbonate system

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Ocean stations of the European infrastructure Integrated Carbon Observation System (ICOS) deliver high quality data to the Carbon Portal (CP) with two main goals: (1) Quantifying air-sea CO_2 fluxes and (2) Assessing the variability and drivers of these fluxes. For goal (1) accurate measurements of surface ocean pCO_2 (better than 2 µatm) are necessary. For goal (2) additional variables of the carbonate system need to be measured.

The marine carbonate system is most often described by four variables: partial pressure of dissolved CO_2 (pCO_2), dissolved inorganic carbon (DIC), total alkalinity (AT) and the pH of seawater. Knowing two of the four carbonate system variables facilitates calculation of the whole marine carbonate system. This can be used to validate the stations core measurement and to deliver against goal (2). The uncertainty of the calculated variables depends not only of the uncertainty of the input variables but also on the uncertainty of the constants that are used.

Several software packages are freely available to perform these calculations. Some of them account for the uncertainty of the input variables and constants and some do not. Here we present the impact of the error propagation considering all sources of error and we compare the output of different software packages. Accounting for all error sources has a strong impact of sampling strategies when validating ICOS-Oceans stations.

Poster presentations in session 3

Characterization of natural gas compressor stations in Ile-de-France regions: CH4 emission rate, C2H6: CH4 ratio, and isotopic signatures

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According to the French national inventories (CITEPA) for the year 2015, the sector of energy transformation contributed 49 kt/y to the national CH_4 emission budget. In this sector, most of the emissions come from the distribution of natural gas. Looking for EDGAR v5.0 inventories, the French CH_4 emission from oil and natural gas sector is estimated at 159 kt/y for the same period. This significant discrepancy between inventories, also observed globally for other inventories, remains challenging to reconcile. The local scale atmospheric measurements can provide additional information to improve the inventory estimates and to understand better the difference between inventories. Additionally, such measurements can inform and help verify effective mitigation strategies. Inside the oil and natural gas sector, the natural gas compressors are one of the potential CH_4 sources. In France, there are 27 natural gas compressors stations, with three of them in the Ile-de-France region. Between 2017 and 2020, the natural gas compressor stations were parts of the sites that we investigated with mobiles CH_4 atmospheric concentration surveys to determine the CH_4 contribution in the Ile-de-France region. In the first stage of our study, we visited all three gas compressors station. In a second step, we focused on one of the compressor stations to make more detailed measurements. Our study is based on in-situ mobile measurements conducted downwind from the source. The CH_4 emission rate is calculated using the tracer dispersion method and Gaussian models. Additionally, C_2H_6: CH_4 ratio and isotopic signatures were determined to characterize better the natural gas distributed in the Ile-de-France region.

Technical note on tall-tower measurement strategy

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Continental greenhouse gas monitoring networks, like that of ICOS, extensively use tall towers for the measurements for higher spatial representativeness. In most cases, taking advantage of the tower, several intakes are built along the tower to give information also on the vertical concentration profile of the component considered. Typically, a single gas analyzer is used, and the intake points are sequentially connected to the instrument. It involves that the continuous concentration signal is only sampled for discrete short periods at each intake points, which does not allow the perfect reconstruction of the original concentration variation. It increases the uncertainty of the calculated hourly averages usually used by the transport and budget models. The poster presents how the uncertainty depends on the number of intakes sampled, on the sampling period at each intake, as well as on the season and the time of the day. The poster also presents how much improvement can be achieved using spline interpolation between the measurement points instead of linear one (arithmetic averaging).

Handling marine carbon data from raw data to data products in respect to the Sustainable Development Goals and the FAIR Data Management Principles

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Some data simply does not meet the criteria for mainstream (often physical) oceanographic data but the demands on how to make it available, perform higher level QC, achieve near real-time (NRT) data products are rising in times of the Agenda 2030 of the United Nations and their Sustainable Development Goals (SDG) where one target (14.3) addresses the Essential Ocean Variable Inorganic Carbon - on top data has to follow the FAIR data management principles. How do adopt new data flows, implement new tools and procedures into established scientific communities?

EOV Inorganic Carbon observations collected from instruments at sea are typically processed by individual PIs before being submitted to data centres and other data archives. Often this work is done on an ad hoc basis using unpublished self-built software and published in unique formats. This leads to lacks in data flow and data availability in respect to SDG target submissions and NRT data availability. Inconsistent data treatment and delivery, lacks of reproducibility are hindering/impeding the Interoperability and Reusability of the FAIR principles since much work is needed to convert data formats while effective re-use of the data is challenging with lacking enriched metadata and details about data processing. If measurements are processed using open source, fully documented standard tools, all data can be traced fully back to source and reassessed if necessary.

The European Research Infrastructure ICOS aims at increasing the fundamental understanding of the marine, atmospheric and ecosystem carbon cycle, it’s underlying processes and verify the effectiveness of policies aiming to reduce greenhouse gas emissions. Within the marine part of ICOS, the Ocean Thematic Centre is developing QuinCe, an browser-based tool for uploading, processing, quality control and publication of data from underway pCO_2 systems on ships, moorings and SailDrones. Data from the instruments can be uploaded directly in any text format, where it will be standardised and processed using algorithms approved by the community. PIs can perform full quality control of the data following SoPs and best practises, which is recorded and then sent to the ICOS Carbon Portal and SOCAT (Surface Ocean CO2 Atlas) project for publication where it is used for decision making and informs the annual Global Carbon Budgets of the Global Carbon Project and can be submitted to the SDG 14.3 target: "average marine acidity measured at an agreed suite of representative sampling stations".

Where data is transmitted directly from ship, mooring or SailDrone to shore, QuinCe processes, quality controls and publishes Near Real Time data to the ICOS Carbon Portal and to Copernicus Marine Environmental Services (CMEMS) as soon as it is received with no human intervention, greatly reducing the time from measurement to data availability and is the baseline for the CMEMS Carbon NRT data product.

All quality control decisions recorded with justifications, so the veracity of all data points can be assured by end users. Standardized vocabularies and metadata formats are compliant with the United Nations Sustainable Development Goal methodology 14.3.1 methodology are applied in the system or will be implemented in 2020.

This contribution will highlight the challenges and achievements of the global marine biogeochemistry community of how to implement new tools, data from new platforms (e.g. SailDrone) and work flows for the Agenda 2030.

A new generation of CO_2 detectors for oceanic pCO_2 measurements

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For the last decades non-dispersive infra-red (IR) analyzers have been the standard detector for equilibrator-based instruments installed onboard ships measuring sea surface pCO_2. Their reliability and ease of use has made them the standard detector. The biggest downfall of these detectors was their drift over time, often correlated with changes in ambient temperature. To measure xCO_2 better than 0.5 ppm it is necessary to regularly measure standard gases. The recommendation is measuring at least three non-zero gases every three hours. Every calibration takes approximately 30 minutes where no environmental data can be recorded.

In 2019 LI-COR brought to market a new type of CO_2 sensor (LI-7815), which is based on the optical feedback cavity enhanced absorption spectroscopy (OF-CEAS), and discontinued their top of the line NDIR instrument. The new sensor is more stable than the older IR systems and is linear over a huge range of CO_2 concentration. This has the potential to require fewer calibration gases and to increase the interval between standard runs, while at the same time increasing the accuracy of measurements. Here we present several months of data where a LI-7815 was connected, together with an LI-7000 NDIR, to an equilibrator-based system (GO pCO_2 system 8050) on board an ICOS SOOP line crossing the North Atlantic Ocean. We compare the quality of both sensors and give suggestions for adjusted calibration runs between the measurements.

ICOS Integrated Carbon Observation System

Atmospheric transport model analysis of methane emissions from oil- and gas-production in Romania observed during the ROMEO campaign in 2019

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Recent studies suggest that methane losses from the oil and gas supply chain are often larger than reported in national emission inventories. According to UNFCCC statistics, one of the most important CH4 emitting countries in the EU due to oil and gas production is Romania, but large uncertainties exist regarding the magnitude of this source. In order to better constrain these emissions, a large measurement campaign ROMEO (ROmanian Methane Emissions from Oil & gas) was organized in autumn 2019 in the framework of the EU project MEMO2, which was funded through the Climate and Clean Air Coalition (CCAC) and administered through the United Nations Environment Program. The campaign involved a large number of European research groups conducting mobile measurements from cars, drones, aircraft as well as on foot. Measurements from cars and drones focused on quantifying emissions from individual wells, while aircraft in situ observations aimed at quantifying emissions from larger oil- and gas-producing regions in addition to on-site measurements.

Here we present an analysis of atmospheric transport model simulations conducted to support emission quantification from the aircraft measurements. High-resolution simulations were per-formed with three different models (COSMO-GHG, COSMO/MESSy, WRF-Chem) for a domain centred over Romania. The models simulated about 40 different CH4 tracers representing emissions from different oil and gas production sub-regions within Romania as well as emissions from other sectors. Detailed location information of oil and gas wells and other production facilities was made available by the largest oil and gas producer in those sub-regions. Location information was supplemented in the model with facility-level emission estimates from a subset of the ground-based measurements. For the comparison with the observations, the model simulations were interpolated in space and time to the aircraft flight tracks.

Observed CH4 enhancements were often well captured by the models, which show that these enhancements were primarily due to oil and gas production. Poor correspondence between simulated and observed concentrations was typically associated with errors in the simulated winds or the height of the planetary boundary layer. For cases where the simulated meteorology agrees well with the observations, the comparison between simulated and observed CH4 concentrations allows an assessment of the emissions of individual production regions.

Session 4: Fluxes at the land-ocean-atmosphere continuum, part 1

Oral presentations in session 4

Dissolved organic matter dynamics across East Anglian river-to-North Sea salinity gradients

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Rivers and estuaries play an important role in the global carbon cycle, representing the interface between the land and the open ocean. Focusing on two lowland UK rivers flowing into the southern North Sea, the River Yare and the River Waveney, this project aims to understand the fate of dissolved organic matter (DOM) as it is transported downstream. Water samples were collected at monthly intervals between December 2018 and December 2019 from seven locations along a salinity gradient on each river, with 179 samples collected in total. Parallel Factor analysis (PARAFAC), fluorescence indices and coloured dissolved organic matter (cDOM) absorption coefficients were measured and used to identify different compounds of DOM to determine its origin (land vs in-situ), its composition (labile vs refractory) and if it was modified during land to sea transport. Dissolved organic carbon (DOC), chlorophyll-a, carbon to nitrogen molar ratios (C:N) and nutrients were also quantified. Results from cDOM analysis, in agreement with the literature, reveal different molecular weight compounds between freshwater and saline water, indicating that photobleaching and/or microbial transformation is occurring as DOM travels downstream. Additionally, PARAFAC analysis identified three components within the rivers: a humic-like, high molecular weight component indicative of terrestrial organic matter; an anthropogenic humic-like component indicative of agriculture or wastewater influence; and a tryptophan-like component indicative of phytoplankton or plants in-situ production. Further research on water samples collected from the North Sea will investigate the fate of DOM, whilst analysis of temporal trends in DOM, nutrients and chlorophyll will explore the seasonal controls on organic carbon dynamics.

Evaluation of a turbulence-based description of the air-water gas transfer velocity

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The physical conditions at the air-water interface drive the efficiency of air-water gas fluxes, often described by the gas transfer velocity. The gas transfer velocity is used to estimate the flux since the flux is difficult and expensive to monitor directly. The gas transfer velocity is commonly parameterised as a function of wind speed. Wind speed directly or indirectly influences most of the processes that control the air-sea gas exchange. However, the wind speed-based parametrisations have a significant spread in their predicted values, in particular for higher wind speeds. This spread does not only result from uncertainties in the measurements, but also on the negligence of underlying processes. The gas transfer velocity is known to be driven by turbulence within the boundary layer close to the air-water interface;

thus, water-side turbulence measurements would be preferable for parameterising the gas transfer velocity.

Here, we use water-side turbulence measurements from an Acoustic Doppler Current Profiler (ADCP) collected in Lake Erken, which is located in east-central Sweden. The ADCP was deployed in lake Erken during two periods in October/November 2018 and February-May 2020. Concurrently, flux measurements of Carbon dioxide (CO_2) and Methane (CH_4) were conducted at a tower, located on an island within the lake, using the eddy covariance method. These measurements allow us to evaluate the relation between water-side turbulence and the gas fluxes, and ultimately the gas transfer velocity.

The analysis is planned to be extended on the air-sea gas exchange in the Baltic Sea. For this, the ADCP is deployed within the footprint of the micrometeorological tower on Östergarnsholm Island. On a global scale, the oceans are a net sink for atmospheric CO_2. On a regional scale, the Baltic Sea varies to be a sink or source for atmospheric CO_2 for different regions and seasons. Coastal areas are less homogenous and more turbulent than the open ocean. The increased turbulence indicate an increased gas exchange. This higher levels of the gas exchange, however, can be reduced by biological productivity.

Here, we present our water-side turbulence and flux observations as well as the analysis on how they are related in Lake Erken. Also, we show how this analysis will be expanded to the Baltic Sea using the Östergarnsholm infrastructure.

Pan-European monitoring of land-ocean-atmosphere carbon fluxes along the aquatic continuum

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The lateral transport of terrigenous carbon (C) along the land-ocean aquatic continuum stimulates a vertical GHG flux, the magnitude of which is significant in terms of GHG accounting at global and regional scales. These lateral and vertical fluxes carry high degrees of uncertainty, thus the sum-total of processes occurring within the land-ocean-atmosphere continuum represents a major gap in the global carbon cycle, and we lack a coherent strategy with which to monitor them at a large scale.

Here we present guidance on the requirements for continual land-ocean-atmosphere C flux monitoring at pan-European scale, including the integration of existing research infrastructure. This includes (1) regular monitoring of lateral (aquatic) fluxes conducted at broad spatial scale by national agencies according to strict site selection and methodological criteria; (2) regular monitoring of vertical (aquatic – sediment and aquatic – atmosphere) fluxes, utilising key 'super sites' at lower spatial resolution; and

(3) process studies, to be conducted by research centres according to bespoke calls on questions of importance. Investment in autonomy is advised, with examples of existing technology given.

The implementation of such a monitoring network will close an important gap in the European carbon budget, and should therefore be established as a matter of importance to ensure data are available in a timely manner. Significant investment and cooperation will be required.

This presentation details the findings of a strategic scoping task that brought together a multi-disciplinary group of experts who are actively investigating the lateral transport of terrigenous organic matter across a range of aquatic environments.

Changes in atmospheric CO_2 over oceans from OCO-2

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The oceans and terrestrial biosphere are the largest sinks of carbon dioxide (CO_2) from the atmosphere. Yet there are significant uncertainties in the ocean-atmosphere CO_2 fluxes, their nature, and evolution. These uncertainties are due to the lack of uniform and dense measurements of CO_2 concentrations in space and time, over the oceans. NASA's Orbiting Carbon Observatory (OCO-2) has been measuring column-averaged, dry mole-fraction of CO_2 (XCO_2) in the Earth's atmosphere since August 2014. OCO-2 data, thus, holds the potential to study the ocean, when supplemented with in-situ ocean measurements. In this study, we present the variability of XCO_2 over the global oceans where regions of positive and negative XCO_2 anomalies overlie the oceans. These patterns are closely related to the dynamical processes and phenomena occurring in different regions of the oceans. As the amount of CO_2 rises due to anthropogenic activities, it affects all the components of the global carbon cycle, including the oceans. Hence, the impact of the ocean processes on the carbon cycle needs further examination. Our study shows the impact of ocean processes on atmospheric CO_2 variability and the contribution of OCO-2 in capturing these variations.

Poor vegetation growth after grassland renewal initially turns bog peatland with submerged drains into a large greenhouse gas source

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Intact peatland ecosystems are efficient sinks of atmospheric carbon dioxide (CO_2). Disturbance, e.g. by drainage to transform peatlands into agricultural land, causes high emissions of the greenhouse gases (GHG) CO_2 and nitrous oxide (N_2O). Our Project "Gnarrenburger Moor" focuses on the evaluation of the effects of submerged drains on GHG emissions and dissolved solute losses from bog peat under intensive grassland management. To facilitate the installation of the water management system, grassland renewal was necessary at one of our two experimental grassland sites, which are located in

Northwest Germany. Here, we report on the initial year of the project focusing on the effects of grassland renewal in combination with rising water levels.

The reference site, representing common region-specific grassland management on peat, is deeply drained by tile drains, while submerged drains were installed at the project site to achieve constantly high water levels of at least 30 to 40 cm below ground. Both sites are equipped with eddy covariance towers for CO_2 measurements and 6 plots for manually measuring N_2O and methane (CH_4) with closed chambers. Water samples for the analysis of dissolved organic carbon, phosphorus and nitrogen species are collected from ditches, tile drains and suction plates at 15, 30 and 60 cm depths. The mechanical renewal in April 2019 involved mulching of the old grass sward and grading the surface of the site. Due to very dry conditions, growth of grass species was poor and the site was mulched and re-seeded again in July 2019. Target water levels could finally be established in September 2019.

During the initial year of our study, grassland renewal substantially dominated the response of the system. From April to December, net ecosystem exchange of the project site was approximately 380 g C m^{-2} higher than that of the reference site. When including carbon input and output from organic fertilizer and harvest, the project site was still by far (around 160 g C m^{-2}) a larger source. When bare soil and rising groundwater levels coincided between July and September, N_2O fluxes rose by a factor of 100 and dissolved nitrogen and phosphorus concentrations also drastically increased at the project site. These N_2O emissions dominated the provisional GHG balance for the first year, which amounts to 89 t CO_2-eq ha^{-1} at the project site in contrast to 16 t CO_2-eq ha^{-1} at the reference site. The next years will show whether an operational water management system and a fully developed grass sward will turn the project site with submerged drains into a smaller source of GHGs than the reference site.

Poster presentations in session 4

The Danube River Delta: CO_2 and CH_4 sources and sinks

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The Danube River Delta is the second largest delta in Europe, comprising of lakes, rivers, channels, and wetlands. This diversity creates a region of vastly differing environments, but closely interlinked with one another. We use high-resolution, spatiotemporal data of CO_2, CH_4, O_2, temperature and conductivity to look closer into these individual regions of the delta. We found supersaturation of CH_4 in the entire delta and distinct patterns of under and super saturation for CO_2. Channels had the largest variability of all systems, showing to be highly influenced by adjacent wetlands varying between ˜32 to over 22,000 µatm for pCO_2 and 221 to 15,600 nmol L^{-1} CH_4. Using mapping and 24-hour cycle measurements we investigated the temporal variation of CO_2 and CH_4 within a lake, finding a strong diel cycle for both gases. This potentially leads to 30 % underestimation of both concentration averages and fluxes for CH_4 when failing to incorporate the full diel cycle into measurements. From the daily surface water cycle, CH_4 production was shown to originate in bottom waters and sediments driving the high overnight concentrations due to daily stratification. For CO_2, biological activities were a strong driver for the consistent undersaturation within the lake we measured, even with a diel variability. These dynamics are not specific for this region as there has been evidence shown before, however allowing for such data could assist with a greater understanding of these regions' explicit sources and sinks.

Alkalinity and dissolved inorganic carbon transported by rivers into the northern Adriatic Sea

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The northern Adriatic is a shallow continental shelf region strongly impacted by rivers discharges, which currently receives about 21 % of the total freshwater input of the Mediterranean Sea. The effects of river nutrients on the trophic state of this coastal marine ecosystem have been largely analysed, but, to date, the knowledge on the riverine transport of dissolved inorganic carbon (DIC) is still limited. Land-borne DIC contributes to the increase of the total alkalinity in the coastal waters, counteracting the acidification process due to the absorption of CO_2 from the atmosphere.

The estimates of DIC river loads were obtained by applying THINCARB model (THermodynamic modelling of INOrganic CARBon) to a compilation of total alkalinity and pH data provided by Research Institutes and Regional Environmental Protection Agencies. The data were collected from 2010 to 2018 for the main rivers flowing into the northern Adriatic Sea (Po, Adige, Brenta, Piave, Livenza, Tagliamento and Isonzo).

The overall river transport of total alkalinity was 205 Gmol yr^{-1}, whereas the transport of DIC was 213 G mol yr^{-1}, of which around 70 % originates from the Po River. About 97 % of the DIC in river water is present in the form of bicarbonate. The mean $\delta^{13}C$-DIC was estimated to be -10 ‰, that is considered today as representative of the DIC riverine inputs in oceanic carbon cycle modelling. Its flux mainly depends by mineral weathering in each river drainage basin, but this process does not exclude the presence of anthropogenic disturbances that should be better analysed.

Preliminary results from a national programme monitoring seasonal variability in air-sea CO_2 exchange and seawater pH in the intermittently stratified "transition zone" of the North Sea

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The North Sea plays an important role in the carbon cycle of the North Atlantic region. It sustains oceanic uptake of CO_2 from the atmosphere via a "continental shelf pump" mechanism in its deeper, seasonally stratified northern part, while releasing CO_2 to the atmosphere in its shallower, permanently mixed south. Between these distinct biogeochemical regimes lies an intermittently stratified "transition zone" that is also influenced by freshwater runoff from the European continent. Here, we present the initial results of an ongoing monitoring programme of 18 stations across the Dutch sector of the North Sea, which falls within this transition zone, and we discuss the policy context for this programme. Each station is occupied monthly and samples are collected for a suite of parameters including total alkalinity, dissolved inorganic carbon, pH, and nutrients. We use the thus over-determined marine carbonate system to investigate the influence of equilibrium constant parameterisation and organic alkalinity on regional air-sea CO_2 exchange and ocean acidification. We evaluate the transition zone in the setting of the wider shelf sea system and consider how interannual variations in its extent and intensity of stratification may influence the overall carbon budget for the North Sea.

Forest floor CO_2 effluxes along a latitudinal gradient

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To estimate, how the global carbon balance in the Northern forest soils will change in a warming climate, the factors controlling autotrophic (RA) and heterotrophic (RH) respiration should be determined in different forest types and climatic conditions. Autotrophic respiration, released by tree roots and root-associated microbes in rhizosphere, was compared to respiration of heterotrophic microbes. This study was implemented at eight measurement sites using a trenching method, where the ingrowth of tree roots was excluded and compared to control plots, where roots were left intact. Soil respiration (CO_2 efflux) was quantified using a static chamber system. Belowground carbon allocation differed between tree species, as the fraction of RA from ecosystem gross primary production (GPP) decreased in Scots pine (Pinus sylvestris L.) forests from subarctic to boreal and temperate climates, but increased in the Norway spruce (Picea abies) forests from north to south in the boreal climate. RH and RA were influenced by the measurement time, soil temperature, soil water content, GPP, soil carbon content and fine root biomass along a latitudinal gradient. The dynamic ecosystem model LPJ-GUESS was able to capture the seasonal dynamic of RH and RA of the different sites, while parameterization of individual respiration components (RH and RA) should be improved in the future.

Impact of applying various prior flux products on estimating CO_2 fluxes derived from the Jena Carboscope regional inversion system

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Regional flux estimates over Europe have been derived from the two-step inverse system of the Jena CarboScope Regional inversion (CSR) to calculate the annual CO_2 budgets for recent years in cooperation with the research project VERIFY. The CSR system assimilates observational datasets of CO_2 dry mole fractions provided by Carbon Portal of the Integrated Carbon Observation System (ICOS) through station network distributed across the European domain. The CSR constrains Net Ecosystem Exchange (NEE) fluxes, which are primarily computed from various biosphere models at a spatial resolution of 0.25 degree against such observational data. To distinguish the impact when applying different terrestrial biosphere fluxes on the a-posteriori in the CSR, the diagnostic Vegetation Photosynthesis and Respiration Model (VPRM), the Simple Biosphere/Carnegie-Ames Standford Approach (SiBCASA), and FLUXCOM model are used as prior biosphere flux models.

Although ocean fluxes are assumed to be constant over time, we assess the sensitivity of the CSR system to using different ocean flux products through assimilating prior ocean fluxes obtained from Mikaloff-Fletcher et al. (2007) and Jena CarboScope pCO_2-based ocean fluxes. Fossil fuel emissions are estimated over countries from EDGAR_v4.3 inventories, updated based on BP statistics.

Results suggest that various prior flux products have no remarkable impact on estimating NEE, which is rather largely constrained by atmospheric observational data. The NEE interannual variability is thus quite dependent upon observations rather than upon prior fluxes, either over domain-wide or at regional scales.

Session 5: Bridging remote sensing and in situ measurements of GHG and related observations

Oral presentations in session 5

Comparisons of AirCore vertical profiles of greenhouse gases from an intensive RINGO campaign at Sodankylä, Finland

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Within the EU-funded Readiness of Integrated carbon observation system (ICOS) for Necessities of integrated Global Observations (RINGO) project, vertical profile measurements have been explored using both AirCores and the ground-based Total Carbon Column Observing Network (TCCON) Fourier-transform infrared spectrometers (FTIRs) to enhance the link between ICOS ground-based stations, TCCON, and satellite measurements. AirCore is a long coiled stainless-steel tube used for atmospheric sampling up to heights of around 30 km, which is launched on a weather balloon with one end open and the other end closed, and collects a continuous ambient air sample during descent. The analysis results of the air samples for greenhouse and other trace gas mole fractions combined with the recorded in-flight information, e.g. coil temperatures, ambient pressure and altitude, allow for the altitude registration of measurements for constructing vertical profiles.

In June 2018, an intensive AirCore comparison campaign took place at the TCCON site in Sodankylä, Finland. A total of 10 balloon flights and 26 vertical profiles were made, with combinations of different AirCores and/or the Lightweight Stratospheric Air (LISA) sampler per balloon flight. The measured species include CO2, CH4, CO, O2, H2O by continuous cavity ring-down spectrometers (CRDS) at Sodankylä, and subsequent isotopic compositions of CO2, CH4 and halogenated trace gases by delayed analyses of collected stratospheric air samples conducted later in several individual home laboratories. Here we present the results from this campaign and compare different AirCore/LISA profiles to show 1) the variability of CO2 mole fractions of AirCore profiles above 20 km is 0.15 ppm; 2) The CO2 observations above 20 km from an AirCore without drying the air sample are on average 0.06 ppm higher than the ensemble mean; 3) the mean column differences between simultaneously collected AirCore profiles are 0 - 0.32 ppm for CO2, 0 – 8.7 ppb for CH4, and 0 – 9.7 ppb for CO, respectively.

Terrestrial laser scanning, the future of forest mensuration at ICOS

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Terrestrial laser scanning (TLS) is a close-range remote sensing tool that is capable of producing astonishingly detailed 3D pointcloud of areas up to several hectares. TLS has become a versatile tool for many forest mensuration applications. In contrast with traditional techniques, TLS allows making precise measurements with minimal impact on the forest, and has as such many potential benefits for long term forest monitoring initiatives. TLS is used to measure DBH and tree height, and also more sophisticated properties like taper curves, tree volume and canopy depth, LAI, 3D stem positions, among many others. Recent years have seen both rapid advances in scanner hardware and profound improvements in software for pointcloud processing.

Using fluxtowers, ICOS ensures high-tech, standardised and continuous measurements of greenhouse gas fluxes at about 40 forest sites. Opportunities for a better understanding of ecosystem functioning arise when coupling these fluxtower observations with the 3D vegetation measurements from TLS. However, till date it is not known whether TLS can meet the stringent data quality demands from initiatives like ICOS. We explore the possibilities of TLS and report from a thorough validation experiment.

We harvested 65 coniferous and deciduous trees after scanning; diameter at breast height and total tree height were estimated accurately with TLS (bias -3% and 0.5%). Using Quantitative Structure Modelling (QSM), we converted pointclouds into complete reconstructions of tree shape. From these models, volumes were extracted, converted into biomass using sampled wood density values, and compared to the weights of the 65 harvested trees. Overall, the QSMs were overestimating biomass by about 20%, largely attributed to an 'inflation' of smaller-sized branches. Branching architecture and crown dimensions were correctly represented. We hypothesize that a combination of wind effects (branches swaying), coregistration error (small shifts in putting different scans into one coordinate system), and range inaccuracies are the main causes of this overestimation. A pragmatic solution in the meantime is to extract the commercial tree biomass (=all parts larger than 7cm diameter) unbiased from QSM and multiply with a biomass expansion factor to obtain above ground biomass. So far, TLS data has been acquired in six ICOS Class 1 Stations. Apart from optimal weather (no wind), which is indispensable for high-quality scans, currently the biggest bottleneck in acquiring forest data from TLS is the laborious post-processing. Efforts to further constrain the errors on biomass estimations with TLS are prioritised. The extraction of several novel forest data products with TLS is investigated.

Greenhouse gas column observations from a portable spectrometer in tropical Africa

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The extensive forest ecosystems of tropical Africa are a significant store of carbon, and play a key but uncertain role in the atmospheric budgets of carbon dioxide and methane. Recent studies of satellite observations have concluded that methane emissions from this geographical region have increased since 2010 as a result of increased wetland extent, accounting for a third of global methane growth (Lunt et al 2019), and that the tropical Africa region dominates net carbon emission across the tropics (Palmer et al 2019). These and other similar studies rely critically on the accuracy of satellite datasets and atmospheric transport models, over a geographical region where there are few independent data to test the robustness of published results.

Here we present the first ground-based observations of greenhouse gas (GHG) columns over East Africa, obtained using the University of Leicester EM27/SUN spectrometer currently located on a year-long deployment from January 2020 at the National Fisheries Resources Research Institute (NaFIRRI) in Jinja, Uganda. The instrument operates near-autonomously by virtue of an automated weatherproof enclosure designed by the Technical University of Munich (Heinle and Chen 2018, Dietrich et al 2019), and is observing total atmospheric column concentrations of carbon dioxide and methane, along with other gases of interest including water vapour and carbon monoxide. We will discuss the overall performance of the enclosure and spectrometer system in this region and present the data obtained so far. The resulting unique dataset will be critical for evaluating current satellite observations and model calculations over East Africa. We will show validation results of satellite GHG datasets from Sentinel 5P, OCO-2 and GOSAT(-2), and assess results from the GEOS-Chem atmospheric chemistry transport model.

Satellite-based analysis on linking photosynthetic activity to different land cover types

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We present an overview of our current work in progress on combining satellite-based land use data with the Nasa Orbiting Carbon Observatory -2 (OCO-2) satellite's solar-induced chlorophyll fluorescence (SIF) measurements, which can be used as a proxy for gross primary productivity (GPP) estimation. This study is a demonstration of a data-driven approach to support the estimation of CO2 emissions and removals from land use, land use change and forestry (LULUCF) with emerging remote sensing opportunities. Pilot areas for our study are Finland and EU. We utilise land use data based on EU Corine Land Cover classification (EU CLC), which is comprised of 14-16 land use classes as proportions of each class inside a 1km x 1km land cover pixel. We cluster the land cover data using k-means algorithm into separate and distinct land use types, and apply this partition to colocated OCO-2 SIF measurements from 2014–2019. The method detects larger average SIF values over agricultural lands in both pilot regions, and smaller averages over deforested and open land. With future satellite missions and their improved spatiotemporal coverage, we expect this type of multi-satellite data analysis to become more frequent in supporting or complementing the national inventory estimates on greenhouse gas emissions and removals at all sectors. Our work offers a promising venue for simultaneous SIF evaluation from in-situ, drone-based and space-based measurements over different land cover types to further evaluate the accuracy and precision of our estimates. In addition, SIF-to-GPP relation over different land cover types still merits further research employing CO2 flux measurements in different regions.

Plausibility, validation and intercomparison of clumping index products from MISR, MODIS, POLDER, and DSCOVR EPIC EARTH observation data over European ICOS RI forest ecosystem sites

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Vegetation foliage clumping significantly alters its radiation environment and therefore affects vegetation growth as well as water and carbon cycles. The clumping index (CI) is useful in ecological and meteorological models because it provides new structural information in addition to the effective leaf area index retrieved from mono-angle remote sensing and allows accurate separation of sunlit and shaded leaves in the canopy. Global and regional scale CI maps have been generated using different approaches from a diverse set of Earth Observation multi-angle datasets across wide range of scales: Multi-angle Imaging SpectroRadiometer (MISR) data at 275 m resolution, the Bidirectional Reflectance Distribution Function (BRDF) product from Moderate Resolution Imaging Spectroradiometer (MODIS) at 500 m resolution, POLarization and Directionality of the Earth's Reflectances (POLDER) data at ~6 km resolution, and most recently from Deep Space Climate Observatory Earth Polychromatic Imaging Camera (DSCOVR EPIC) at 10 km resolution. In this presentation, we characterize and intercompare seven available CI products over 20+ forest ecosystem sites, organized within the European Integrated Carbon Observation System (ICOS) research infrastructure, representing diverse forests with different canopy structures. The intercomparison procedure was defined to comply with the best practices proposed by CEOS (Committee on Earth Observation Satellites) Land Product Validation (LPV) sub-group. It corresponds to Stage 1 validation as defined by the CEOS. We illustrate that the vertical distribution of foliage and especially the effect of understory needs to be taken into account while validating foliage clumping products from Earth Observation data with values measured in the field. Satellite measurements respond to the structural effects near the top of canopies, while ground measurements may be biased by the lower vegetation layers. Additionally, caution should be taken regarding the misclassification in land cover maps as their errors can be propagated into the foliage clumping maps. Our results indicate that the selected datasets can provide good quality clumping index estimates at pertinent scales for modeling local carbon and energy fluxes. As a part of the analysis, we carry the assessment of spatial representativeness of individual ICOS forest ecosystem sites in validation of satellite retrievals. Our results improve our understanding of product uncertainty both in terms of the representativeness of the field data collected over ICOS sites and its relationship to Earth Observation data at different spatial resolutions.

Poster presentations in session 5

Vertical Distribution of Arctic Methane in 2009–2018 Using Ground-Based Remote Sensing

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We created a time series of vertical profiles of methane (CH_4) concentration using ground-based short wave infrared spectra measured by a Fourier Transform Spectrometer (FTS) in Sodankylä, Finland. The retrieved data set covers years 2009–2018 and an altitude range of 0 to 40 km. For the retrieval we used a dimension reduction method. In our method the vertical variability in the methane concentration are described with four singular vectors derived from the prior covariance matrix.

We compared the retrieved profiles to the Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS) satellite measurements and the AirCore balloon-borne profile measurements. The lowest retrieved layer was also compared to in-situ measurements from a 50-meter mast. In general, the ground-based FTS and ACE-FTS profiles agreed within 10% below 20 km and within 30% in the stratosphere between 20 km and 40 km.

In addition to one-to-one comparison we also used dynamic linear model (DLM) to calculate smoothed growth rates over the time series from the retrieval and the instruments used as the reference. Our method produced similar trend characteristics as the references. Our trend estimates suggest that the most recent tropospheric CH4 growth rate in Sodankylä has been lower than the global average while the stratospheric growth rate has become stronger, which may point to an enhanced circulation from the tropics or to a decrease in the stratospheric methane sink.

This method could be used to improve the temporal coverage of profile measurements of greenhouse gases. As the balloon-borne and aircraft measurements, even though very accurate, are quite time-consuming and require a lot of resources, they are not performed very frequently. The satellite measurements using solar occultation, such as ACE-FTS, also have better vertical resolution but the revisit time is irregular and infrequent.

Atmospheric column measurements of greenhouse gases by remote sensing techniques: from validation to network extension

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Recent satellite measurements of greenhouse gases (GHG) allow near real time monitoring of the atmospheric column abundance with an unrivaled spatial coverage (GOSAT, OCO-2, OCO-3, TANSAT). Over the next few years, similar satellites will be equipped and launched, among which the MicroCarb mission which is driven by CNES (France) for CO2 measurements (2021) and the MERLIN mission jointly managed by the CNES and the DLR (Germany) for CH4 measurements. These space missions have to be validated and calibrated by ground-based remote sensing measurements, which also derive GHG column abundance but are much more reliable as they are not affected by the back-scattered solar radiation and are regularly calibrated.

Thus, space borne measurements are currently evaluated by comparison to the high-spectral resolution FTIR of TCCON ground based spectrometers (Total Carbon Column Observing Network). This network of approximatly 25 stations covers mostly the mid-latitudes of the northern hemisphere.

A major shortage for satellite validation is the lack of column measurements in the tropics. Indeed, spatial observations have shown significant structures in the tropical regions which have sometimes been questioned due to the atmospheric and surface conditions affecting the measurements.

To bridge this tropic gap, the compact and lightweight EM27 FTIR spectrometer seems promising. Since 2018, LSCE, CNES, LERMA and GSMA are building a French EM27 network including 5 instruments, a data base for automatic data treatment, a calibration central facility and the development of a standalone waterproof casing. These developments are done in the scope of a potential extension of the network in the tropics: Ivory Coast and Amsterdam Island (Indian ocean).

This presentation gives a first overview of recent development operated by the French EM27 consortium, together with the possibilities offered by the EM27 spectrometers in terms of measurement validation and comparisons with TCCON and AirCores. Results from intensive field campaigns at the Trainou ICOS super-site will be shown.

Variations in seawater mixing and ice concentration as main drivers for changes in methane over the Arctic seas: satellite data

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Spectrometers using the outgoing long-wave IR (thermal) radiation of the Earth in sun-synchronous polar orbits provide a wealth of information about Arctic methane (CH4) year-round, day and night. Their polar night data are unique. The report analyzes concentrations of methane obtained by the AIRS and IASI spectrometers in conjunction with microwave satellite measurements of sea ice concentration and ECCO model for the seawater mixed layer depth. The data were filtered out for cases of sufficiently high temperature contrast in the lower atmosphere. The focus is on the Barents and Kara Sea during autumn-early winter season between 2003 and January 2020. These seas underwent dramatic decline in the ice cover during last 17 years. This shelf zone is characterized by huge reserves of oil and natural gas (~ 90% methane), as well as presence of sub-seabed permafrost and methane hydrates. Seasonal cycle of atmospheric extra-methane (surplus over Atlantic) has a minimum in early summer and a maximum in early winter in accordance with changes in the depth of mixed layer. During last 17 years both summer and winter concentrations were increasing, but with different rates. In winter the Kara Sea methane was growing faster than that over Atlantic. The seasonal cycle amplitude tripled from 2003 to 2019. In the same time the fraction of ice-free sea surface quadrupled. If the current Arctic sea cover would decline further and open water area would grow then further increase of methane concentration over the ocean may be foreseen.

Session 6: Budgets, trends, and controls of GHG and other atmospheric constituents, part 1

Oral presentations in session 6

The value chain of ocean CO2 measurements

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The oceans take up a quarter of the carbon dioxide (CO2) emissions from human activity, as well as 90% of the excess heat. This ocean CO2 uptake mitigates climate change, while also profoundly changing the carbonate chemistry of the oceans, a process referred to as ocean acidification. A value chain based on in situ inorganic carbon measurements of the ocean and shelf seas provides policy makers with essential information on ocean CO2 uptake in climate negotiations. This presentation considers the elements of the value chain.

Marine carbon scientists around the world have made in situ, high-quality measurements of inorganic carbon variables in the ocean and shelf seas since 1957 with a strong increase in the data collection effort from the 1990s onwards. These measurements are made on research ships, commercial ships (known as 'ships of opportunity'), moorings and on drifting and autonomous surface platforms. The measurements are put in a uniform format, quality controlled, assembled and made publicly available in two, community-led synthesis products, SOCAT (the Surface Ocean CO2 Atlas, www.socat.info) for the surface ocean and GLODAP (the Global Data Analysis Project, www.glodap.info) for the interior ocean. These data products form the basis for the quantification of air-sea CO2 exchange, its multiyear variation and of the progression of ocean acidification. They are also used for evaluation of sensor data and of ocean biogeochemical models, which forecast ocean CO2 uptake under different CO2 emission scenarios. The results of these activities provide input to the Global Carbon Budget, the Intergovernmental Panel on Climate Change and to other high-profile scientific assessments, which in turn inform the climate negotiations of the United Nations Framework Convention on Climate Change (UNFCCC). A feedback from the UNFCCC via the Global Climate Observing System (GCOS) relates policy needs for specific measurements back to the data providers.

High-quality, long-term, in situ ocean measurements of inorganic carbon variables form the basis of the value chain. Without them there would be no data-based estimates of ocean CO2 uptake and models would lack evaluation against in situ data. It is therefore a grave concern that about 80% of the supposedly 'sustained' ocean observations are funded by short-term research projects. The global need for accurate knowledge of ocean CO2 uptake and its variation requires a new funding model for in situ ocean observations of inorganic carbon variables.

CarbonWatchNZ: Regional to National Scale Inverse Modelling of New Zealand's Carbon Balance

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Atmospheric observations of CO2 and other greenhouse gases have been widely used to constrain estimates of terrestrial and oceanic CO2 fluxes through atmospheric inverse modelling. Yet, applying these methods at national scale to verify and improve the National Inventory Report (NIR) and support the Paris agreement remains at the frontier of CO2 science.

In the CarbonWatchNZ project, we combine measurements with models to develop a complete top-down picture of New Zealand's carbon balance, by studying the three landscapes that are most important to New Zealand's carbon emissions and uptake: forest, grassland and urban environments. In addition to quantifying New Zealand's carbon emissions on a national scale, we also focus on identifying the prevailing processes driving CO2 changes in New Zealand to support climate mitigation.

In an initial study based on the inversion system used in CarbonWatchNZ, a significantly stronger (30-60 %) sink was found relative to the NIR (Steinkamp et al., 2017), suggesting a strong CO2 uptake in Fiordland, a region covered by indigenous temperate rainforest in New Zealand's Southern Island. Here, we present new results of CarbonWatchNZ by expanding the studied time period from 2011-2013 to 2020, expanding our atmospheric observing network from two (Baring Head, 41.41°S, 174.87°E and Lauder, 38.33°S, 176.38°E) to a total of eleven in situ greenhouse gas measurement sites, and improving our atmospheric model resolution by roughly a factor of ten (NAME model, 1.5 km).

Our new results suggest that the strong sink observed in 2011-2013 did not diminish, but for recent years we have found and even stronger sink than for before. Additional measurements collected in the Fiordland region (i.e., CO2 isotopes, carbonyl sulphide) also suggest a stronger CO2 uptake, supporting our inversion results. Implementing observations from an additional site in the North Island (Maunga Kakaramea, 45.034°S, 169.68°E) have additionally increased the strength of the sink, pointing to additional strong sink region at the top of the North Island.

Factors affecting the air-sea CO2 flux in the Arctic Ocean in summer

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The Arctic Ocean is a sink for carbon dioxide (CO2) due to the high solubility of CO2 in cold water and high primary productivity in the summer. However, direct flux measurements of air-sea CO2 transfer are very scarce for the Arctic Ocean. In consequence, there is a poor understanding of gas transfer processes in its sea-ice covered areas, which is an obstacle to robust estimates of air-ice-sea gas fluxes. We measured eddy covariance CO2 fluxes during two cruises to the Barents Sea and the Greenland Sea during summer 2019. Preliminary analysis indicates that the waters were a summertime CO2 sink with regional variations and there are shallow stratifications in the ice melt regions. We will use these measurements to investigate how factors like ice coverage and primary production affect air-sea CO2 fluxes, and to constrain the magnitude of near-surface stratification in seawater CO2 concentration. Air-sea CO2 concentration differences were also measured during the second cruise and we will present and discuss the gas transfer velocity variations during this period.

Simulations of atmospheric CO_2 and $\delta^{13}C$-CO_2 compared to real-time observations at the high altitude station Jungfraujoch

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Evaluating atmospheric transport simulations against observations helps refining bottom-up estimates of greenhouse gas fluxes and identifying gaps in our understanding of regional and category-specific contributions to atmospheric mole fractions. This insight is critical in the efforts to mitigate anthropogenic environmental impact. Beside total mole fractions, stable isotope ratios provide further constraints on source-sink processes.

Here, we present two receptor-oriented model simulations for carbon dioxide (CO_2) mole fraction and $\delta^{13}C$-CO_2 stable isotope ratios for a nine year period (2009-2017) at the High Altitude Research Station Jungfraujoch (Switzerland, 3580 m asl). The model simulations of CO_2 were performed on a 3-hourly time-resolution with two backward Lagrangian particle dispersion models driven by two different numerical weather forecast fields: FLEXPART-COSMO and STILT-ECMWF. The STILT simulations were performed through the ICOS Carbon Portal ""on-demand calculator"" (https://stilt.icos-cp.eu/worker/). Anthropogenic CO_2 fluxes were based on the EDGAR v4.3 emissions inventory and aggregated into 14 source categories representing fossil and biogenic fuel uses as well as emissions from cement production. Biospheric CO_2 fluxes representing the photosynthetic uptake and respiration of 8 plant functional types were based on the Vegetation Photosynthesis and Respiration Model (VPRM). The simulated CO_2 mole fractions per source and sink category were weighted with category-specific $\delta^{13}C$-CO_2 signatures from published experimental studies. Background CO_2 values at the boundaries of both model domains were taken from global model simulations and the corresponding $\delta^{13}C$-CO_2 values were constructed as suggested in Ref. We compare the simulations to a unique data set of continuous in-situ observations of CO_2 mole fractions and $\delta^{13}C$-CO_2 stable isotope ratios by quantum cascade laser absorption spectroscopy as described in previous work, available for the whole nine year period at the site.

The simulated atmospheric CO_2 and $\delta^{13}C$-CO_2 time-series are in good agreement with the observations and capture the observed variability at the models' 3-hourly time-resolution. This allows for an in-depth evaluation of the contribution of different CO_2 sources and sinks to the mole fractions ob-served when Jungfraujoch is influenced by air masses from the planetary boundary layer. In brief, the receptor-oriented model simulations suggest that anthropogenic CO_2 contributions are primarily of fossil origin (90%). Anthropogenic emissions contribute between 60% in February, and 20% in July/August, to the regional CO_2 mole fractions. The remaining fraction is due to biosphere respiration, which thus largely dominates source-related mole fractions during the summer season. However, in-tense photosynthetic uptake during June, July and August roughly outweighs CO_2 contributions from anthropogenic activities and biosphere respiration at JFJ.

Substantially larger estimates of global ocean-atmosphere fluxes of atmospheric CO_2 from surface data obtained when temperature corrections are applied

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Reliable estimates of ocean-atmosphere fluxes, both regionally and globally, are critical to determining the fate of human emissions of CO_2. In recent years an international effort has resulted in the free availability of quality-controlled data sets for fCO_2, the surface ocean carbon dioxide fugacity, enabling a number of time-resolved calculations of ocean-atmosphere fluxes of CO_2. However, previous studies have not corrected the data for temperature gradients between the surface and sampling depth at a few metres or for the effect on fluxes of the cool ocean surface skin. Here we calculate a time history of ocean-atmosphere fluxes of CO_2 from 1992 to 2018 corrected for these effects. These increase the calculated net flux into the global oceans by 0.8-0.9 $PgCyr^{-1}$ over this period, at times doubling the uncorrected values. We estimate the uncertainty in our flux calculations by using both simple and sophisticated interpolation methods, but all configurations give convergent results when estimating fluxes globally after about 2000, or over the northern hemisphere throughout the period. Our corrections reconcile surface fluxes with independent estimates of the increase in ocean CO_2 inventory. Comparison with the inventory suggests that the pre-industrial flux of CO_2 from the open ocean to the atmosphere was ~0.5 PgC yr^{-1} and that it exhaled mostly from the southern hemisphere.

Poster presentations in session 6

Biological and physical controls on Water Use Efficiency across contrasting ecosystems in the alpine region

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Water use efficiency (WUE) is the parameter linking the gross primary productivity (GPP) and evapotranspiration (ET) at the ecosystem level. Besides the recent modelling efforts and advances in this topic, the main driving factors for GPP/ET ratio (WUE) are still poorly understood. We performed a comprehensive study across six different typical Alpine ecosystems, spanning a sub-humid apple orchard, an irrigated and a rainfed pasture, a deciduous and an evergreen coniferous forest and a high elevation alpine grassland, for a total of 18 site-years. The overall goal of the research was the understanding of the variables dictating the water-carbon exchange and feedback at the regional scale.

All the sites, in two cases belonging to the ICOS infrastructure, were equipped with the eddy covariance instrumentation. We took into account the temporal evolution of the leaf area index (LAI) and, for forests, we considered the independently measured sap flow to partition the transpired component from the total ET flux. After having established a selection criterion for meteorological and eddy covariance data, we calculated the evapotranspiration at all the sites according to the Penman-Monteith equation. The linear regression between Penman-Monteith ET and eddy covariance-based ET presented coefficients of determination ranging from 0.56 to 0.87. To understand the physical role of aerodynamic conductance, we inverted the Penman-Monteith equation to obtain the canopy and aerodynamic conductance. Given the understanding of the energy imbalance in eddy covariance sites, latent and sensible heat half-hourly fluxes were adjusted by a factor that closes the energy balance on monthly intervals.

Our results show that both biological and physical variables play a role in WUE determination, and different factors can prevail at specific sites. A general feature is that at all the sites LAI evolution in time largely drives the WUE, while climate variables such as mean annual temperature are relatively less important.

Ocean carbon exchange and drivers from winter to summer in the Atlantic water inflow to the Arctic Ocean

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The eastern Fram Strait and area north of Svalbard, are influenced by the inflow of warm Atlantic water, which is high in nutrients and CO2, influencing the carbon flux into the Arctic Ocean. However, these estimates are mainly based on summer data and there is still doubt on the size of the net ocean Arctic CO2 sink. We use data on carbonate chemistry and nutrients from three cruises in 2014 (January, May, and August) and one in Fram Strait (August). We describe the seasonal variability and the major drivers explaining the inorganic carbon change (CDIC) in the upper 50 m, such as photosynthesis (CBIO), and air-sea CO2 exchange (CEXCH). Remotely sensed data describes the evolution of the bloom and net community production. The focus area encompasses the meltwater-influenced domain (MWD) along the ice edge, the Atlantic water inflow (AWD) and the West Spitsbergen shelf (SD). The CBIO total was 2.2 mol C m-2 in the MWD derived from the nitrate consumption between January and May. Between January and August, the CBIO was 3.0 mol C m-2 in the AWD, thus CBIO between May and August was 0.8 mol C m-2. The ocean in our study area mainly acted as a CO2 sink throughout the period. The mean CO2 sink varied between 0.1 and 2.1 mol C m-2 in the AWD in August. By the end of August, the AWD acted as a CO2 source of 0.7 mol C m-2, attributed to vertical mixing of CO2- rich waters and contribution from respiratory CO2 as net community production declined. The oceanic CO2 uptake (CEXCH) from the atmosphere had an impact on CDIC between 5 to 36%, which is of similar magnitude as the impact of the calcium carbonate (CaCO3, CCALC) dissolution of 6% to 18%. CCALC was attributed to be caused by a combination of the sea-ice ikaite dissolution and dissolution of advected CaCO3 shells from the south. Indications of denitrification were observed, associated with sea-ice meltwater and bottom shelf processes. CBIO played a major role (48 to 89%) for the impact on CDIC.

A satellite-based long-window/short-window inversion setup to estimate global CO_2 fluxes

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Biogenic carbon exchange at the Earth's surface is still characterized by a high uncertainty, both with respect to interannual and small-scale variations. Net ecosystem exchange (NEE) estimates can be obtained by flux inversion systems that assimilate atmospheric observations, either from high-precision in situ measurements or lower precision remote-sensing products. Data records from in situ observation sites often span several years or even decades, and are therefore suitable to study long-term trends in land and ocean fluxes. However, due to the sparse coverage of observation locations and the poorly known error covariance structure, the resulting spatial NEE patterns remain to a large extent determined by the patterns present in the prior estimate. On the other hand, retrieval products of satellite-based column CO_2 abundances (XCO_2) are characterized by a nearly global coverage and high resolution, but with much shorter records. XCO_2 inversions with a short assimilation window may thus yield valuable information about small-scale flux variations, both in space and time, and can thus augment inversions based on flask or in-situ records such as collected through ICOS.

Therefore, we present an innovative 2-step data assimilation approach for estimating biogenic CO_2 fluxes on a global to regional scale. The first step accounts for the seasonal to decadal variations and large-scale flux patterns. It consists of a long-window inversion (LWI) in which we optimize the parameters in a statistical description for the long-term regional mean NEE, constrained by flask-based atmospheric CO_2 observations only. This part makes sure that large-scale mean fluxes, seasonal cycle and the long-term trends are in line with observations. As a second step, small-scale NEE variations in space and time are optimized by means of a short-window inversion, constrained by satellite-based XCO_2 observations. The LWI results then act as part of the prior NEE, but we optimize small-scale flux deviations from modeled hourly local NEE fluxes, using a significantly smaller assimilation window (several days). With this 2-step inversion approach we aim to efficiently make full use of the small-scale information included in satellite observations, while at the same time also constraining the large-scale patterns by observations. ICOS observations of CO_2 mole fractions thus form an essential ingredient for the development of this setup, both to constrain fluxes in the LWI component, and for validation of regional NEE patterns over Europe derived from XCO_2.

Carbon uptake by Subantarctic Pacific waters

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The Southern Ocean absorbs ~40% of the global oceanic anthropogenic CO_2, therefore, playing a crucial role in the global carbon cycle. The importance of the Southern Ocean in the global carbon cycle is a consequence of the direct connection between the surface and deep ocean through isopycnal ventilation and formation of mode, intermediate and bottom waters. The CUSTARD project hypothesises that the interplay between ocean surface biogeochemistry, circulation and remineralisation controls the amount of carbon taken up by the Southern Ocean, therefore, determining how long carbon entering the Southern Ocean is stored. To probe the hypothesis, the CUSTARD process cruise was conducted along 90°W during the dynamic spring period of 2019-2020, crossing the subantarctic front (57-58°S) to just north of the polar front (60-63°S). To study the importance of the processes affecting the carbon uptake during the CUSTARD cruise, we decomposed the observed dissolved inorganic carbon (DIC_obs) into the contributions of the carbon pumps (Volk & Hoffert, 1985), i.e., the solubility pump (or physical pump; DIC_sol), the biological pump (DIC_soft), and the carbonate pump (DIC_carb): DIC_obs = DIC_sol + DIC_soft + DIC_carb. In this work we examine and present the results of the carbon pumps to assess how the region stores and exports carbon. The temperature contribution to the DIC distributions is observed in DIC_sol. The progression of the phytoplankton bloom can be traced by DIC_soft, being the removal of surface DIC by DIC_soft and DIC_carb higher in the southernmost stations than in the northernmost stations. A further look based on water mass circulation in the region will give us insights into the linkage between the depth of the carbon pumps' signals and the water masses, therefore linking back to the CUSTARD objectives of assessing the long-term storage of carbon by the Southern Ocean.

Modeling the atmospheric fluxes in a sub-alpine critical zone monitoring network, Col du Lautaret, French Alps

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Mid-altitude mountainous ecosystems constitute a sensitive corridor subjected to both climate variability and human pressure. The former impacts snowpack dynamics, which is expected to change from a full continuous snow season to an intermittent coverage and disappearance. The latter operates through atmospheric transport and deposition of pollutant, through new species introductions and land use changes. This collectively puts 'extreme' pressure on critical zone functioning. More specifically, anthropogenic reactive nitrogen deposition in alpine meadows has been shown in some areas to exceed critical loads, leading to potential changes in ecosystem dynamics from growth acceleration to biodiversity changes. In this study we aim to quantify nitrogen transfers from deposition on snow to outflow in a small sub-alpine mid-altitude (2000-2200 meter) mountainous ecosystem throw a Critical Zone coupled modelling approach of Nitrate, CO2 and water cycles. The modelling results will be validated with the observational data available at sources and sinks (H2O, CO2, N) of a small catchment (15.3 ha) at Col du Lautaret in the French Alps. The study will help to reveal the fact about the nitrate availability and its consumption in the watershed. It will also tell the lag of nitrate magnification and movement over time. As nitrogen (nitrate) is limiting agent to primary production, so overall study will help to introspect the effect of anthropogenic forcing on the biodiversity of sensitive ecosystem. The site provides an ample of research opportunity due to its ecosystem and availability of qualitative analysis of different physical and chemical parameters. As a part of database building, we also have the continuous chemistry monitoring at Col du Lautaret through very advance and sophisticated methods like ion chromatography and isotope fractionation, especially for the nitrate monitoring. This presentation will show the first simulation results on water fluxes from a fully distributed and integrated coupled atmospheric-hydrologic model ParFlow-CLM (PF-CLM). The model is calibrated for one hydrologic year 2017-2018 and resolved for different parameters like evapotranspiration, water pressure, overland flow, saturation through different non-linear equation solver. Further, these outputs were used as an input to the Lagrangian particle tracking model, EcoSLIM, to simulate the path and residence of water and material in solution within the watershed. This will be compared to characteristic chemical reaction times to formulate assumptions on the fate of reactive nitrogen along the Critical Zone path within the watershed.

Impact of Amazon propagation on the air-sea flux of CO_2 from model and observations

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The surface fugacity of CO_2 (fCO_2) has been measured hourly at a mooring at 8°N, 38°W, using a spectrophotometric CO_2 sensor, from June to October 2013. In September 2013, the fCO_2 and the sea surface salinity (SSS) decrease significantly. The high precipitation due to the presence of the Intertropical Convergence Zone (ITCZ) and the propagation of low salinity waters from the Amazon River plume explain the decrease of SSS. Indeed, in fall, the retroflection of the North Brazil Current (NBC) feeds the North Equatorial Counter Current (NECC) and transports Amazon waters to the eastern part of the tropical Atlantic. Simulations from a three dimensional physical and biogeochemical model and observations at the mooring show that the Amazon plume reached the mooring in September 2013.

The decrease of fCO_2 is associated with a moderate peak of chlorophyll. Over the period of the CO_2 observations, the site is a source of CO_2 to the atmosphere of 0.65 ± 0.47 mmol $m^{-2}d^{-1}$. Although the wind speed is at its lowest intensity in September 2013, the flux over the whole period would be about 14% higher without this month. Every month of September from 2006 to 2017, the model simulates a decrease of dissolved inorganic carbon corresponding to the SSS minimum.

In-situ continuous atmospheric greenhouse gases (CO_2, CH_4 and CO) measurements at the OHP ICOS-Fr station tall tower in South France from July 2014 to March 2020 and related anthropogenic tracers

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The Observatoire de Haute Provence (OHP; 43° 55' 51" N, 5° 42' 48" E, 650 ASL) belongs to the ICOS-France greenhouse gases monitoring network and is operational since July 2014. It is located about 100 km north of the Aix-Marseille metropolis in the SUD-PACA region, which is characterized by a Mediterranean climate. According to IPCC (2013), the SUD-PACA region is much exposed to the risks of climate change, which include perturbations of the carbon cycle at the local to the regional scales. The OHP station is equipped with a tall tower of 100 m agl. A Picarro G2401 CRDS analyzer monitors continuously atmospheric CO_2, CH_4 and CO at three different levels alternatively every 20 minutes (10m,50m, 100m agl). For each level, meteorological parameters (pressure, temperature, relative humidity, wind speed and direction) are also continuously recorded. Surrounded mainly by white oak trees, the ICOS-Fr OHP station is set-up in a rural environment, allowing to follow the long-term evolution and variability of background CO_2 and CH_4 in the SUD-PACA region. However, depending on synoptic conditions and on the season, anthropogenic emissions (for example from the Aix-Marseille metropolis) can increase the greenhouse gases concentration levels at the station. In this study, six years of atmospheric CO_2, CH_4 and CO continuous measurements (from July 2014 to March 2020) were analyzed to assess the variability of CO_2 and CH_4 at different spatio-temporal scales. Regarding CO_2 and CH_4, respectively, we inferred that the annual growth mean at OHP is about +2.7 ppm/year and +7.9 ppb/year; the amplitude of the mean seasonal cycle is about 13 ppm and 44 ppb ; and the amplitude of the mean diurnal cycle varies from 3 ppm (4 ppb) in winter to 11 ppm (8 ppb) in summer. The frequency and intensity of synoptic and short-term variability of CO_2 and CH_4 will also be presented in this poster. Correlations of CO_2 and CH_4 with CO, but also with particulate matter (PM10 and PM2.5) and ozone, monitored at 4 m agl at OHP by the regional air quality agency (ATMOSUD), were also investigated to better infer the role of natural vs anthropogenic fluxes on atmospheric CO_2 and CH_4 variability at OHP.

Atmospheric O_2 and CO_2 exchange in a boreal forest in Hyytiälä, Finland

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Photosynthesis and respiration of carbon dioxide (CO_2) by forests are two major unknowns in understanding the impacts of rising atmospheric CO_2 levels on future climate. Using combined atmospheric O_2 and CO_2 measurements, this project aims to provide new insights in the forest carbon balance. The method is based on the inverse relationship between oxygen (O_2) and CO_2 found over forests: when trees take up CO_2 from the atmosphere through photosynthesis, they release O_2, while respiration of CO_2 by trees consumes O_2 from the atmosphere.

Field campaigns have been conducted in a boreal forest in Hyytiälä, Finland in spring/summer 2018 and 2019 for several weeks each year. The measurements have been done at two levels in the main measurement towers: at 23m just above the canopy and at 125m. The gradient between the two levels is used to derive the flux of O_2. The measurements are extended with observations of vertical profiles of temperature and humidity, obtained from radiosondes. Furthermore, additional measurements are used from the well-established atmospheric and ecosystem station, including Eddy covariance flux observations and temperature gradients.

At the conference we will show first measurement results for selected days, in combination with an analysis using a mixed layer model. These first results show the challenges to measure atmospheric O_2 gradients in a forest environment and the possibilities to use these towards a better quantification of the forest carbon balance.

Can we see it? How in situ observation networks may detect environmental impacts on ecosystem biogeochemistry

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The ICOS network of Ecosystem station is monitoring the greenhouse gases fluxes, carbon, energy and water balances and phenology on the long term (20 years) at an hourly resolution with a high level of standardisation. We have analysed its performance in terms of sensitivity using a simple variance model of ICOS observed variables. The variance model sums of a temporal drift, a natural temporal variability and a measurement error. The monitoring duration, size of the stations network, and measurement accuracy needed for detecting a temporal change in observed variable could thus be determined. The variance components were calibrated using legacy data of eddy covariance towers reprocessed homogeneously (Fluxnet 2015, Pastorello et al. 2020). We applied this analysis to the detection of the effect of the increase in atmospheric CO2 concentration on different time integrals of GPP, from half hourly to annual. We show that the sensitivity to CO2 differs significantly among plant functional types and conclude that the network sensitivity can be magnified when selecting appropriate indicators, such as the half-hourly values of maximal GPP.

The same analysis was then applied to the ICOS network of stations for the upcoming 30 years. First, the putative impacts of future changes in ozone and nitrogen depositions, CO2 concentration and climate were first mapped across Europe at a 50 km resolution, as simulated by the chemistry transport model MOCAGE (Météo-France). Then, the capability of the ICOS network of Ecosystem stations to evidence these impacts on European ecosystems was assessed. The results obtained were finally used for proposing an optimal design of the Ecosystem station network in terms of network size, geographical coverage and metrological performances.

Pastorello G. et al. 2020. The FLUXNET2015 dataset and the ONEFlux processing pipeline for eddy covariance data. Nature, Scientific data. In revision, April 2020.

A Case study on early snowmelt and its influence on seasonal carbon uptake in an alpine meadow (Col du Lautaret)

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Mountain ecosystems are under pressure from climate change and from anthropogenic influence. However, assessing their evolution in the future remains complicated, partly because of the scarcity of data available to assess current models of surface exchanges in those highly variable areas.

The seasonal variability in the surface exchanges of the subalpine grassland, FR-Lau, located at the Col du Lautaret, was investigated using the eddy covariance methodology, combined with vegetation and meteorological measurements. The mass exchanges were characterized before and during the growth vegetation period during two contrasted years in 2017 and 2019. Based on the cumulative soil temperature, the albedo, NDVI (Normalized Difference Vegetation Index) and other variables, the growing period was characterized for both years. Flux data provided by the FluxAlp tower were gap filled and partionned following nighttime methodology (Reichstein et al. 2005) in order to quantified the Net Ecosystem Exchange (NEE), the Gross Primary Production (GPP) and the Ecosystem Respiration (Reco). Specifically, the study focused on the impact of an early snow melt on the vegetation growth and on the ecosystem productivity.

In 2017, an early snow melt was observed (day 124), followed by a new snowfall. This melting was linked with an increase of the air and soil temperatures. The end of the snow melt in 2017 and 2019 was around the same date (day 135) but with a cumulative soil temperature of 85°C in 2017 against 60°C in 2019. This difference of cumulative temperature influenced the vegetation growth. In 2017, the NDVI curve followed the average NDVI dynamic of the 2012-2019 period. The duration of the vegetation growth season was 142 days in 2017 for an average duration of 142.4 days over 2012-2019. The onset point occurred on the 22nd of May (day 142), that is the average onset day and the peak of the growing season was reached 6 days after the 2012-2019 average one (day 180 and day 174 respectively). The NDVI in 2019 increased later (4 days after) and slower than in 2017. The NDVI reached its maximum 16 days later in 2019 than in 2017. The same dynamic was observed for GPP: the peak was reached 20 days later in 2019. GPP was therefore higher during the growing season in 2017 (897 $gC.m^{-2}$) than in 2019 (693 $gC.m^{-2}$). At the end of the hydrological year, 2019 was a source of carbon with a NEE of +170 $gC.m^{-2}$ whereas FR-Lau was a sink of carbon in 2017 with a NEE of -239 $gC.m^{-2}$. Compared to 2017, the later onset of the snow melt paired with lower cumulative temperature in 2019 directly influenced the difference observed on the dynamic of the vegetation growth.

These results suggest that in those alpine meadows, not only the timing, but the history of snowmelt plays an important role in the net seasonal carbon uptake. This ecosystem had a highly sensitive response to edaphic and meteorological variations. A long term observation of mountain sites is needed in order to better understand the seasonal biophysical processes of such ecosystems in response to climate change.

Mid-latitude North Atlantic CO2 fluxes and biogeochemical/physical drivers of their variability

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The ocean uptake of natual and anthropogenic carbon is not constant over time or regular on seasonal or annual time scales. Together with the air-sea CO2 flux being influenced by biogeochemical as well as physical processes, the ocean uptake of CO2 is in itself influencing ocean conditions including ocean acidification.

As the majority of models are unable to accurately re-produce the contemporary variability or trend of the air-sea CO2 flux, modelled predictions contain high spread of the future air-sea flux evolution estimates.

In order to be able to improve models and hence future predictions, on which policy, societal, and economic strategies are based, high quality ocean observations are essential. The North Atlantic is one of the ocean basins with the highest number of observations, including those made on ICOS stations. In-depth studies of these observations can help us identify the required frequency and resolution on which observations need to be continued on a sustainable basis in this region, and they can help identifying observational requirements in other less-observed ocean basins.

We will present an in-depth study of the air-sea CO2 flux variability in this region, based on ocean and atmospheric observations made on on marine ICOS stations. We will address the drivers of the observed variability, utilising satellite, in situ, and re-analysis data products of biogeochemical/physical parameters influencing the ocean uptake of atmospheric CO2 from seasonal through interannual time-scales. Understanding the CO2 flux together with the drivers of its variability enables us to help improve ocean, climate, and general circulation models.

5-year analysis of near-surface atmospheric CO2 in Italy by a collaborative network of four permanent observatories

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We analysed a set of continuous measurements of carbon dioxide (CO2) carried out at 4 atmospheric observatories in Italy from 2014 to 2018: Plateau Rosa (PRS), Mt. Cimone (CMN), Capo Granitola (CGR), and Lampedusa (LMP). The network spans from the Alpine region to the central Mediterranean Sea. All the considered sites contribute to the WMO/GAW programme. Mt. Cimone is also a “class-2” ICOS station, while Plateau Rosa and Lampedusa are in the labelling process. Marked differences exist at the considered sites, mostly due to the different geographical and environmental locations which lead to different exposure to regional CO2 sources and sinks. A methodology for the selection of atmospheric background CO2 data (background data selection for Italian stations, BaDSfit) was tested at each measurement site and optimal algorithm settings were proposed, based on the reduction of time variability and daily cycle, and background CO2 time series were derived. The BaDSfit algorithm leads to identify as non-background conditions about 4% of the data at LMP, 7% at PRS, 19% at CMN and 61% at CGR. A latitudinal dependence in the annual cycle amplitude emerges when background data are analysed. These results suggest that the adopted algorithm is capable of separating of local/regional scale from large scale phenomena in the CO2 time series. A similar interannual variability was found for the yearly average background CO2 values among the sites. The availability of two co-located measurement laboratories at CMN, provides the opportunity to discuss the impact of

Regional Terrestrial Ecosystem Carbon Flux Constrained with New Ground CO2 Observations in China

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Atmospheric inversions using in-situ CO2 observations agrees well on global carbon budget estimates but differ greatly on regional carbon flux estimates and the partitioning of land and ocean flux as well, mainly due to the uneven spatial distribution and sparseness of observations in remote regions. Especially, there are only two stations in China publicly available for inversions. The ground CO2 concentration observations at five other sites from the China Meteorological Administration, provide an opportunity to better constrain the inversion of the terrestrial ecosystem carbon flux in China and its adjacent regions. In this study, regional terrestrial ecosystem carbon flux is constrained with CO2 concentration observations from both ObsPack and these five stations in China, using the GEOS-Chem four-dimensional variational (4D-Var) data assimilation system. The inverted monthly terrestrial ecosystem carbon flux at TRANSCOM regions from 2007 to 2016 is presented. The impact of the addition of those five stations on the inversion result in China and its adjacent regions will be analyzed.

Biological and Environmental Controls on Evaporative Fraction of a multi-cropland site in southern Italy

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The evaporative fraction (EF) defined as the ratio between latent heat (LE) fluxes and the sum of LE + sensible heat (H) is a biophysical parameter that reflect the distribution of surface available energy, interpreting the components of energy budget and used as drought index.

By using a partial correlation and a stepwise multiple regression analysis we identify the main environmental drivers of the EF in a multi-cropland site in southern Italy and its relationship with the Net Ecosystem production (NEP). The study was carried out on a farm located in Southern Italy (Borgo Cioffi, Eboli, Italy 40º31' 25.5" N, 14º57'26.8" E) the European southernmost cropland observation candidate site of ICOS. The site was cultivated with silage Cor (Zeal mays L. cv Mazdoor Calcio) as main crop, in rotation with Lolium (Lolium perennial L) and Fennel (Funiculus vulgare).Our preliminary results indicate that micrometeorological observations e.g. Soil water Content (SWC), canopy temperature (Tcan), Vapor Pressure Deficit (VPD), and the Stomatal conductance (Gs), can be used to predict the EF at daily and monthly time step: the comparison between the EF observed and the multiple regression output (monthly time step) indicates an Adjr2 of 0.67 for corn, 0.50 for Ryegrass/clover and 0.42 for Fennel. The relationship between EF and daily NEP in the main crop (Corn) of the rotation were all significant at $p < 0.05$ with the Adjr r2 ranging from 0.11 to 0.66 while this relationship was higher (Adjr r2 0.51 $p < .05$) at low level of SWC (5 < SWC < 15) compared to a more a moisture conditions that present an Adjr r2 of 0.32 $p < .05$ (15 < SWC < 30) and Adjr r2 of 0.25 $p < .05$ (SWC > 30). The use of EF as drought index, in Corn cultivations, was evident in two distinct episode characterized by a rapid decline of the SWC when (i) the EF dropped from 0.8 to 0.4 resulting in a simultaneous reduction of the C uptake (from -15 g C m-2 Day-1 to – 0.48 g C m-2 Day-1) and (ii) the EF dropped from 0.7 to 0.3, and the C uptake has been reduced from – 6 g C m-2 Day-1 to 0.27 g C m-2 Day-1. The preliminary results of this study indicate that EF can be used as drought index in cropland to optimize the irrigation calendar and water use.

Session 7: Urban observations and detection of human emission, part 2

Oral presentations in session 7

Compiling a more complete inventory of public power and heat plant point source emissions in the EU

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Public power and heat (PPH) plants continue to make an important contribution to the total (anthropogenic) emissions of the greenhouse gas CO_2 and several co-emitted species (e.g. NOx, CO, SOx, PM) in the European Union. These hotspots are associated with large local concentration gradients in the atmosphere, making the availability of accurate information on the emission levels important for modelling of greenhouse gases and the interpretation of in-situ and satellite observations. Emission data for individual plants from annual reporting under the EPRTR regulation (European Pollutant Release and Transfer Register) is published in the EPRTR dataset. This dataset constitutes the most accurate and up-to-date public data source on these emissions.

The inclusion criteria for these reporting obligations, however, lead to issues for the completeness of the dataset. Due to relatively high and static reporting threshold values for the EPRTR (e.g. 100 kt for CO_2 and 500 t for CO), smaller plants are mostly missing from the dataset. Furthermore, even for medium-sized and larger plants, emission reporting is often incomplete and more gaps occur over time due to implementation of abatement measures causing emission levels to drop below the threshold value. This presents a challenge to the coverage of the dataset and thereby its practical application in atmospheric modelling and analysis.

To illustrate the problem: in 2017, out of ~2130 plants in the PPH sector reporting emissions in the EPRTR dataset, only ~970 plants reported CO_2 emissions. The total emission levels represented 83% of sector totals in national CO_2 reporting. A similar observation can be made for NOx, while for CO, only ~100 PPH plants reported emission in the EPRTR dataset, covering 65% of reported sector CO emissions in 2007, but only 39% in 2017.

We developed a gap-filling routine that uses additional datasets and plant- and country-specific pollutant ratio's to compile a more complete and consistent spatial emission dataset for PPH plants in the EU for years 2000–2017. An additional feature of this dataset is that emissions are split between main fuel types, facilitating more detailed analyses related to changes in the fuel mix or the use of tracers such as atmospheric potential oxygen (APO).

We will show that the new dataset improves the coverage of point source emissions compared to reported sector totals for CO_2 from 83% to 95% and from 80% to 86% for NOx. While these increases seem modest with regard to absolute emission levels, the importance of the gap-filling process is highlighted by the increased number of PPH plants included for each pollutant: For CO_2 gap-filling almost doubles the number of plants included from 968 to 1826, while for CO only 94 plants were reporting in EPRTR, which is increased to 1710 plants in our dataset.

These results show that our effort significantly ameliorates the problem of incomplete emission reporting for medium-sized plants, which is important for local air quality modelling. For small PPH plants that fall outside of the reporting, this method is unsuitable and more work needs to be done to incorporate them in an emission dataset.

Monitoring ffCO$_2$ emission hotspots using atmospheric $^{14}CO_2$ measurements

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Reliable estimates of fossil fuel CO_2 (ffCO$_2$) emissions from regions or urban areas are currently in demand from a wide range of players. On the one hand, cities and municipalities themselves are interested in an independent validation of their ffCO$_2$ emissions. On the other hand, there is an increased interest in atmospheric science to merge independent emission estimate methods over different scales. $^{14}CO_2$ has become the gold standard when it comes to the experimental splitting of atmospheric CO_2 concentration into its biogenic and fossil components.

Here we report on the identification of ffCO$_2$ emitted from the Mannheim/Ludwigshafen metropolitan region in the upper Rhine valley, Germany. Quantification of the regional ffCO$_2$ component requires knowledge of the composition of the background air. Thus, the emission area has been sampled by an upwind and a downwind station. We will discuss the advantages and disadvantages of using local background measurements conducted at a dedicated upwind station of the emission area and compare this realisation of background estimate to regional background estimates derived from measurements at classical remote background sites. All CO_2 and $^{14}CO_2$ observations have been performed as part of the European RINGO project. Furthermore, we investigate the suitability of using the total-CO_2 difference between the two stations as a proxy for fossil fuel CO_2 and the seasonal applicability of such a surrogate tracer. Finally, the observations of the total-CO_2 surrogate tracer will be compared with the predictions from STILT forward model runs.

Tracking the Nature of Urban Carbon Cycle – the Introduction of Megacity CO_2 – Seoul Project

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Assessment of urban carbon cycle is a critical issue to understand the global carbon cycle. In addition, exact assessment on urban carbon cycle should be the first step to make a better solution to reduce anthropogenic carbon emissions from urban area. To understand the source and sink of atmospheric CO_2over the Seoul Capital Area (SCA), where is one of the apparent Megacities across the world, we develop "Megacity CO_2-Seoul project" in the year 2019. In this initiative, we establish the ground-based CO_2concentration measurements from low- to high-cost devices such as Li-850 NDIR and Piccaro CRDS sensors. Besides, to further understand the carbon flux over the SCA, we have 14 urban eddy-covariance flux towers across the city. As a first project year, all measurements are well established to keep monitoring $CO_2$and carbon fluxes. In this presentation, we will introduce the details in "Megacity CO_2-Seoul project" and show up some key results from the first year monitoring such as urban CO_2enhancement, altitudinal features in urban atmospheric CO_2, dominant wind speed effect on urban CO_2enhancement.

Assessing the constraint of the CO2 monitoring mission on fossil fuel emissions from power plants and a city in a regional carbon cycle fossil fuel data assimilation system

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The Paris Agreement foresees to establish a transparency framework that builds upon inventory-based national greenhouse gas emission reports, complemented by independent emission estimates derived from atmospheric measurements through inverse modelling. The capability of such a Monitoring and Verification Support (MVS) capacity to constrain fossil fuel emissions to a sufficient extent has not yet been assessed. The CO2 Monitoring Mission (CO2M), planned as a constellation of satellites measuring column-integrated atmospheric CO2 concentration (XCO2), is expected to become a key component of an MVS capacity. A companion abstract assesses the potential of a global-scale Carbon Cycle Fossil Fuel Data Assimilation System (CCFFDAS) to constrain country-scale fossil fuel CO2 emissions from synthetic CO2M XCO2 observations.

Here we present a CCFFDAS that operates at the resolution of the CO2M sensor, i.e. 2km by 2km, over a 200 km by 200 km region around Berlin. It combines models of sectorial fossil fuel CO2 emissions and biospheric fluxes with the Community Multiscale Air Quality model (coupled to a model of the plume rise from large power plants) as observation operator for XCO2 and tropospheric column NO2 measurements. Inflow from the domain boundaries is treated as extra unknown to be solved for by the CCFFDAS, which also includes prior information on the process model parameters. We discuss the sensitivities (Jacobian matrix) of simulated XCO2 and NO2 troposheric columns with respect to a) emissions from power plants, b) emissions from the surface and c) the lateral inflow and quantify the respective contributions to the observed signal. The Jacobian representation of the complete modelling chain allows us to evaluate data sets of simulated random and systematic CO2M errors in terms of posterior uncertainties in sectorial fossil fuel emissions. We provide assessments of XCO2 alone and in combination with NO2 on the posterior uncertainty in sectorial fossil fuel emissions. Further, we quantify the effect of better information of atmospheric aerosol, provided by a multi-angular polarimeter onboard CO2M, on the posterior uncertainties.

Initial assessments show that XCO2 measurements provide a strong constraint on fossil fuel CO2 emissions of large power plants. The fossil fuel emissions of the other sectors are only weakly constrained at the spatial scale of a 2 km by 2 km pixel but moderately when aggregated over the whole area of Berlin.

Urban greenhouse gas monitoring in the Greater Toronto Region, Canada

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Future population growth and greenhouse gas emissions will be centered in urban areas and already today over half of the world's population live in metropolitan areas. While emissions of carbon dioxide and some air pollutants can be estimated quite precisely on national scale using fuel consumption statistics, urban emission inventories have considerably larger uncertainties of 20%-50%.

In Canada, over 70% of the population resides in urban areas. The Greater Toronto and Hamilton Area (GTHA) is home to ca. 7 million people and is expected to grow by 1.5 Million inhabitants by 2030, while the city and region have announced ambitious greenhouse gas emission reduction targets. Environment and Climate Change Canada has been performing in-situ measurements of atmospheric greenhouse gases and their isotopic compositions in the GTHA for over a decade. In recent years, ground-based remote sensing and vehicle-based surveys have been added to the set of regular activities in collaboration with the University of Toronto. We strive to provide actionable information to a variety of stakeholders and align with the principles of WMO's Integrated Urban Greenhouse Gas Information System (IG3IS).

Here, we present the key findings derived from our long-term observations at four atmospheric monitoring sites related to trends of the local atmospheric enhancements of CH_4 and CO_2, as well as changes in isotopic compositions. Our more recent mobile surveys have also lead to an improved understanding of the spatial distribution of atmospheric CH_4 and the importance of different emission sectors. Lastly, measurements by the ground-based remote sensing network have shown cross-city enhancements in total column greenhouse gas levels.

Poster presentations in session 7

Impact of a landifll fire on the atmospheric greenhouse gases and aerosol properties at Lampedusa

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A large fire started on 12 June, 2019, at the local landfill site on the island of Lampedusa (35.5°N, 12.6°E). The fire remained active for at elast 24 hours, and a dense smoke covered the area. The smoke plume is visible also in MODIS satellite images on 12 June.

On the island of Lampedusa, about 6 km ENE of the landfill site, the ENEA Atmospheric Observatory (http://www.lampedusa.enea.it) has been measuring a large set of atmospheric parameters. CO2, CH4, and CO are continuously measured with a CRDS instrument together with meteorological parameters, and these measurements contribute to the ICOS atmospheric network.

A significant enhancement of the atmospheric CO2 was observed on 12 June, with mixing ratios values reaching 416-417 ppm, with respect to a pre-fire value of about 410 ppm. Enhanced CO2 mixing ratio lasted for about 20 days, suggesting that emissions continued in a smouldering phase after the active fire was suppressed. Modifications in the emission regime appear to be supported by the evolution of CO and CH4, which do not follow the same pattern as CO2, with a delayed increment for CO, and a much smaller variaton for CH4. Black Carbon evolutio, conversely, appears to be in a very good correlation with CO2. The event has been investigated also taking into account meteorological patterns and the PM10 chemical compositions. Optical properties and radiative effects of the aerosol were also investigated. The large and relatively long-lasting impact of the fire appear to be also connected with the boundary layer inversion regime which develops over the region in summer, and prevents a strong vertical mixing of the emitted compounds.

Atmospheric Δ_{47} as a tracer for local atmospheric CO_2 sources and sinks - a theoretical analysis of mixing effects

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Δ_{47} is a widely used tracer for temperature reconstruction in paleo-science. It is defined as the relative excess of CO_2 isotopologues with an atomic mass of 47u (mainly $^{18}O^{13}C^{16}O$) over the abundance of these isotopologues under a stochastic distribution. The temperature dependency of Δ_{47} gives the possibility to differentiate between high temperature (e.g. by burning fossil fuels) and low temperature sources (e.g. soil respiration). Furthermore, measuring Δ_{47} might provide more insights into mass dependent fractionation effects.

Here we present a theoretical study using synthetic data which examines the effect of mixing different source signals into an ambient air mass. The informative value of the measurement of Δ_{47} under current and possibly improved measurement uncertainties and under CO_2 enhancements at typical atmospheric sites is examined. Furthermore, it is shown how to calculate Δ_{47} under mixing conditions without producing nonlinearities, which have occurred in previous studies [Eiler et. al. (2004), Affek et. al. (2005), Defliese et. al. (2015), Laskar et. al. (2016)]. In this feasibility study we show, with synthetic data, how regular atmospheric Δ_{47} measurements can be used, and demonstrate their limits. It will be completed by the presentation of first results from our measurements in Heidelberg.

The CO2 Emissions of US Cities: Status, Dynamics, and Comparisons

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Urban areas are rapidly growing and are acknowledged to dominate greenhouse gas (GHG) emissions to the Earth's atmosphere. They are also emerging as centers of climate mitigation leadership and innovation. However, fundamental quantitative analysis of urban GHG emissions beyond individual city case studies remains challenging due to a lack of comprehensive, quantitative, methodologically consistent emissions data, raising barriers to both scientific and policy progress. Here we present the first such analysis across the entire US urban landscape, answering a series of fundamental questions about emissions responsibility, emissions drivers and emissions integrity. We find that urbanized areas in the U.S. account for 68.1% of total U.S. fossil fuel carbon dioxide (CO2) emissions. Were they counted as a single country, the 5 largest urban emitters in the US would rank as the 8th largest country on the planet; the top 20 US cities as the 5th largest. In contrast to their dominant overall proportion, per capita FFCO2 emissions in urbanized areas of the US are 7% less than the country as a whole, particularly for onroad gasoline emissions (-12.3%).

Contrary to previous findings, we find that emissions grow slower than urban population growth in Eastern US cities, particularly for larger urban centers. The Western US, by contrast, shows emissions growing proportionately with population. Much of the difference between Eastern versus Western cities is determined by the onroad emissions sector. This finding, in particular, suggests that "bigger is better" when considering GHG emissions and U.S. urban population growth.

Finally we find large and persistent differences between the results presented here and 57 self-reported urban inventories. The mean difference between the self-reported inventories and the analysis here is -24% (mean absolute difference: 44.3%) with the majority of self-reported values lower than quantified in this study.

Evaluating anthropogenic CO2 emissions of China estimated from atmospheric inversions of "proxy" species against tower CO2 measurements

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Accurate estimation of anthropogenic CO2 emissions (ACE) is of great importance for climate change mitigation, however, it is quite challenging. Co-emitted gases, e.g. CO and NOx, are proved to be useful for tracking ACE. Here we estimated ACE of China based on "proxy" species (i.e. CO and NOx) inversions with emission ratios of CO2 and the "proxy", and evaluated the estimates using tower CO2 measurements in population-dense areas based on the Stochastic Time-Inverted Lagrangian Transport (STILT) modeling driven by the Global Data Assimilation System (GDAS) meteorology. An ensemble of ACE of China was estimated from different combinations of anthropogenic CO or NOx flux estimates and emission ratios, where the CO or NOx fluxes were estimated from in-situ measured concentration data or satellite column concentration data, and the emission ratios were derived from two emission inventory datasets, i.e. multi-resolution emission inventory for China (MEIC) and global emission inventories by Peking University (PKU-FUEL). We found all CO2 simulations with "proxy" based ACE estimates (either using in-situ or satellite data) clearly fitted better to observations than those with inventory datasets did, especially during around winter time (October to March in the next year). Meanwhile, clear mismatches between simulations and observations were found for some periods, which indicated the use of CO or NOx to track ACE is not suitable for a whole year. Our result demonstrates the potential to use atmospheric "proxy" species to track anthropogenic CO2 emissions in China, and the data assimilation system optimizing ACE fluxes with "proxy" species is under development.

Continuous observation of CO_2, O_2 and radon in Bern city are complemented with their stable isotope measurements to partition CO_2 emissions into biogenic and specific fossil fuel contributions

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Since 2003 onwards, continuous measurements of CO_2 and O_2 are being performed at the roof of our institute at the University of Bern located in the center of Bern city, Switzerland. These measurements are being done by a nondispersive infrared analyser (CO_2) and a paramagnetic principle (O_2). The measurements are complemented with discrete isotope ratio measurements on CO_2 and O_2 and additionally with O_2/N_2, Ar/N_2 and CO_2/N_2 ratios by means of mass spectrometry. The data document the CO_2 increase and corresponding O_2 decrease due to the oxidation of fossil fuel emissions. Furthermore, they can be used to partition the CO_2 emissions into biogenic and fossil fuel contributions

based on the oxidation ratio (DO_2/DCO_2). Using the correlation of short term variations of radon as well as CO_2, mean flux densities can be estimated. An customized radon tracer inversion allows to estimate the spatial and temporal distribution local CO_2 emission fluxes.

Evaluation of the measurement quality through the comparison of two high alpine CO2 records at the Jungfraujoch (Switzerland)

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Since 2003, continuous measurements of CO_2 are ongoing at the Sphinx observatory that is part of the High Altitude Research Station located at the Jungfraujoch (Swiss Alps, 3570 m a.s.l.). Since December 2014, we have an additional location available for research at the Jungfrau East Ridge (3690 m a.s.l.) around 1 km westward from the Sphinx observatory that is not accessible for tourists and thus well suited to compare air quality measurements to those recorded at the Sphinx observatory. A Picarro G2311-f laser based instrument has been installed in the East Ridge building which is continuously measuring the CO_2 mole fraction in the atmosphere that can be compared with the Sphinx data to investigate the potential pollution inherent to anthropogenic activities at the Jungfraujoch. Agreement between both CO_2 records is good but exhibits annually averaged daily differences of less than 1 ppm whereas the corresponding nighttime values are within the measurement precision matching the WMO compatibility value of 0.1 ppm and thus can be considered as background air CO_2 mole fraction. Input from air masses seems to be responsible for the longer variability, whereas diurnal spikes that occurs essentially in summer are likely to result from local emission source. Our preliminary results from CO_2 measurements show the suitability of the East Ridge as an additional new location to perform high quality atmospheric measurements.

Assessing Emission Characteristics of Cities Using Satellite-based Observations of CO2, CO, and NO2

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With increased urbanization across the world, cities have been growing rapidly, and intensified human activities and high levels of energy consumption in such areas have led to the increase in emissions of CO2 and air pollutants which have a great impact on air quality. We explore the possibility of monitoring urban enhancements of CO2 using observations from NASA's Orbiting Carbon Observatory-2 (OCO-2) and of air pollutants CO and NO2 from ESA's Sentinel-5 Precursor TROPOspheric Monitoring Instrument (S-5P TROPOMI) in Northern Hemisphere cities during the winter season. We use satellite observations to analyze urban enhancements of ΔXCO2, ΔXCO, and XNO2 and enhancement ratios, ΔXCO/ΔXCO2 and XNO2/ΔXCO2, according to each city to observe the relationship between CO2 and air pollutants as well as the emission patterns of cities.

Our analysis shows a positive relationship in the comparisons of ΔXCO/ΔXCO2 and XNO2/ΔXCO2 to city population and GDP, indicating that the size of the city and its economy can act as defining factors of air quality. However, when cities were divided into 'developed' and 'developing' regions, a difference in pattern was found where developing cities facing rapid economic development show high emission ratios that almost matched that of developed cities. The high emission ratios of ΔXCO/ΔXCO2 and XNO2/ΔXCO2 in these cities can be attributed to the low combustion efficiency of fossil fuels along with less stringent pollution control measures. The comparison also highlights the importance of geographical features surrounding the city which trap air pollution when coupled with meteorological conditions. Despite the short period of analysis, our study shows that comparing satellite observations of CO2 and air pollutants can provide clues about factors and sources that affect air quality in cities, and synergies of future satellite missions with longer periods of observation will aid in policymaking for effective pollution reduction.

The potential of satellite spectro-imagery for monitoring anthropogenic CO_2 emissions from large point sources and cities in Europe

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The development of systems for monitoring of anthropogenic CO_2 emissions strongly relies on new-generation satellite missions dedicated to observing column-average CO_2 dry air mole fraction (XCO_2). Several missions of high-resolution spectro-imagery are currently planned, with the capability to observe XCO_2 plumes downwind of large cities and industrial plants across the globe, including the Copernicus Anthropogenic Carbon Dioxide Monitoring (CO2M) Low Earth Orbit constellation (ESA/EU), which will be deployed from 2025. In the frame of the TRAcking Carbon Emissions (TRACE) program, we study the potential of such an observation concept for monitoring the emissions at scales ranging from point sources to regional scales. We perform Observing System Simulation Experiments (OSSEs) over Western Europe by coupling radiative transfer and atmospheric transport models. The radiative transfer inversion propagates uncertainties from the radiance measurements to the XCO_2 retrievals, and then the transport model inversion estimates the CO_2 emissions under various surface and atmospheric conditions. These inversions allow assessing the sensitivity of the CO_2 concentration and emission estimates to the mission and instrumental specifications. This presentation details the radiative transfer and atmospheric inversion frameworks. The atmospheric inversions rely on a zoomed configuration of the CHIMERE regional transport model with a 2 km resolution over Northern France, Western Germany, and Benelux. Maps of XCO_2 sampling and errors associated with the concept of XCO_2 spectro-imager close to CO2M are presented as well as uncertainties in the estimate of emissions from ~300 large industrial plants and cities in this area of interest over March and May in 2016. The targeted sources and the period of analysis cover a wide range of emissions spread and rate and of meteorological conditions for each source, which allows for analyzing results as a function of such parameters. We analyze “posterior uncertainties” in the inverted estimate of emissions and “uncertainty reductions” by comparing them to “prior uncertainties” in the estimates from the inventories used as a prior knowledge in the Bayesian framework of the inversions. Results highlight the strong dependence of uncertainty reductions on the emission budgets and whether we focus on point or regional sources. For the budgets of emissions within the 6-hours before a satellite overpass, uncertainty reductions of more than 50% can only be achieved for power plants and cities whose annual emissions are more than ~2 MtC/yr. For regions (including cities and plants), this threshold increases up to ~10 MtC/yr. Accounting for spatial correlations in XCO_2 retrieval errors impacts these results in a way that depends on the source extension and rate, errors with short (0-2 km) or long (>50 km) correlations being easier to filter than those with correlation length scales close to the size of plumes. The presentation concludes on the need for strengthening the coupling of the radiative transfer and atmospheric transport models in view to better address such correlations.

Session 8: Vulnerability of the Carbon Cycle, part 1

Oral presentations in session 8

Short-term impacts of the summer 2019 heatwave on ecosystem functioning inferred from ICOS flux towers in France

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The frequency and intensity of extreme weather events are increasing in response to climate change. Among such events, heatwaves impact both public health and ecosystem functioning. In France, in 2019, two heatwaves took place between June and August, lasting however only a few days each. While the historical temperature record was broken at the end of June 2019, the intensity and duration of those two events differed between regions of France. In forests and crops, warm temperatures, together with moderate soil drought, led to a reduction in photosynthetic activity, inducing a loss of ecosystem productivity and carbon (C) sequestration. In particular, crop management, such as irrigation, could play an important role. In peatlands, the potential effect of heatwaves is more uncertain, as they often develop in humid areas.

This study aimed at (i) describing how 2019 heatwave events impacted C and water vapour (H_2O) fluxes at several forest, cropland and peatland sites within the ICOS ecosystem network in France, covering several soil, climate and vegetation conditions and (ii) exploring the physiological processes affected by the heatwaves. At all sites, CO_2 and H_2O fluxes, measured by eddy-covariance according to the ICOS protocols, were analysed to infer heatwave impacts on net ecosystem exchange (NEE), gross photoynthesis (GPP), ecosystem respiration (Reco), and evapotranspiration. Canopy conductance (gc) was inferred from evapotranspiration by inverting the Penman-Monteith equation.

For forest sites, the heatwave generally caused a reduction of gc, especially after midday, which indicates a stomatal closure in response to higher VPD observed in the afternoon. This was concurrent with reduced NEE. Depending on sites, the forest would switch from a C sink to a C source, or become a weaker C sink, with total or only partial recovery after the heatwave. GPP was generally lower during the heatwave, again with total or partial recovery. Ecosystem respiration appeared to be stimulated by the higher temperatures, but frequently displayed inconsistent responses, possibly due to issues with partioning algorithms. At FR-Pue, where temperatures were the highest, the heatwave caused immediate, partial leaf mortality.

Peatlands displayed no noticeable change in gc during the heatwaves, possibly due to surface temperatures not being as high as in forests, except for FR-LGt, where temperatures were higher and gc was reduced. That site became a stronger source of CO_2 during the heatwave.

For crop sites, the most noticeable impacts were observed at the three maize-cropped sites, among which both FR-Gri (Paris area) and FR-Mej (Brittany) exhibited reduced photosynthetic activity and stomatal conductance (both up to about 50 %) in July, as plants had reached their maximal leaf development and soil moisture availability was limited. At the FR-Lam site, where maize was irrigated, no reduction in photosynthetic activity was observed; total crop production was even larger than usual.

Heatwaves will become more common under climate change. Our results indicate that they will likely diminish ecosystems C sequestration. While the measured responses were expected (stomatal closure, its impact on photosynthesis, and increased respiration), modelling such events remains a challenge.

How nutrient and water availability impact carbon fluxes in a semi-arid tree-grass ecosystem

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Semi-arid ecosystems play a major role in the global carbon cycle. Their high intra and inter-annual variability in water availability is driving their carbon cycle and the sink or source strength of these ecosystems. Additionally, nutrient availability plays a big role in these ecosystems to modulate carbon uptake, ecosystem respiration as well as transpiration. To disentangle these different effects and the impact of different drivers for the carbon balance, and processes driving the carbon cycle we conducted a large-scale experiment in a semi-natural agroforestry ecosystem in the center of the Iberian Peninsula. The MaNiP experiment aims to understand the role of nutrient availability and stoichiometric imbalance of nitrogen and phosphorus to in modulating carbon and water interactions. To do so three eddy covariance tower footprints ~ 24 ha were used as treatments of which two were fertilized with nitrogen (NT) and nitrogen + phosphorus (NPT) and the third served as the control treatment (CT). Further we followed a precipitation gradient from mean annual precipitation of 650 to 350 mm and set up an additional eddy covariance site in a dryer but very similar ecosystem, to understand how processes and ecosystem functional properties related to the carbon cycle change.

Due to the fertilization schemes we observed changes in: the above and below ground biomass, leaf nutrient content, carbon and water fluxes, and in the speed of the regreening after the summer drought. While increased nitrogen availability enhanced the development of biomass during the growing period and thus carbon uptake, it also reduced evaporation from the soil as higher leaf area index resulted in less available energy at the soil surface. The stoichiometric imbalance (wide N:P ratio at NT with potential P limitation) resulted in increased transpiration and changes in root growth towards higher root density in the top soil. With high N and high P availability transpiration was reduced and no changes in root growth were detected. Overall, the high availability of N resulted in increased carbon uptake at the fertilized treatments which drove the increase on the water use efficiency of both treatments compared to CT. The increased transpiration at NT reduced the WUE compared to NPT and was a result the vegetation to increase P-uptake from the soil.

The analysis of the precipitation gradient revealed that gross primary productivity of the dryer ecosystem is more sensitive to reductions in precipitation/soil water content as compared to the wetter site. This is especially true for the spring and autumn (the regreening of the ecosystem) period. Additionally, it is important to mention that the wetter site shows especially during the summer period stronger respiration fluxes which are most likely due to deeper soil water availability from a thick clay layer.

Ecosystem functioning and recovery after two consecutive extreme years in Switzerland

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The summer of 2018 was among the most extreme summers ever recorded in Europe: remotely sensed vegetation indices show that in large parts of the continent, the 2018 drought even exceeded the hot drought of 2003. The following summer, 2019, exceeded the conditions of 2018 in terms of air temperature and replaced the position of the third warmest year ever recorded in Switzerland. In this context, the resilience of the ecosystems in terms of sequestration of atmospheric CO2 and modulating the climate (through evapotranspiration, ET) remains unclear.

Using eddy covariance measurements from two contrasting forest sites we estimated changes in net ecosystem productivity (NEP) and ecosystem underlying water use efficiency (WUEu) in response to drought. In 2018, in the low-elevation mixed deciduous forest (at 682 m a.s.l.) gross primary productivity (GPP) declined compared to the previous two years which led to a reduced NEP, despite lengthening of the growing period. In the high elevation coniferous forest (at 1639 m a.s.l.), however, GPP increased in response to increased temperatures, but this was combined with an increased ecosystem respiration which reduced NEP. The underlying water use efficiency of both forests increased in response to drought, with a more pronounced increase for the coniferous forest. We assess ecosystem recovery based on the link between ecosystem productivity (i.e. GPP) and water use (i.e. ET) during non-limiting moisture conditions (i.e. wet soil and low atmospheric vapor pressure deficit, VPD) following moisture-limited periods (dry soil and high VPD) and show a comparison of responses in 2018 with those in 2019.

ICOS Integrated Carbon Observation System

Non-stomatal processes reduce gross primary productivity in temperate forest ecosystems during severe edaphic drought

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Severe drought events are known to cause important reductions of gross primary productivity (GPP) in forest ecosystems. However, it is still unclear whether this reduction originates from stomatal closure (Stomatal Origin Limitation) and/or non-stomatal limitations (Non-SOL). In this study, we investigated the impact of edaphic drought in 2018 on GPP and its origin (SOL, NSOL) using a data set of 10 European forest ecosystem flux towers. In all stations where GPP reductions were observed during the drought, these were largely explained by declines in the maximum apparent canopy scale carboxylation rate VCMAX,APP (NSOL) when the soil relative extractable water content dropped below around 0.4. Concurrently, we found that the stomatal slope parameter (G1, related to SOL) of the Medlyn et al. unified optimization model linking vegetation conductance and GPP remained relatively constant. This result was unexpected as it implies that NSOL (instead of stomatal closure) was the main process limiting GPP during drought.

The Integrated Ocean Carbon Observing System

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The Oceans have taken up 20-25% of the carbon dioxide released to the atmosphere by human activities, in the process slowing the rate of climate change and giving us more time to adapt to and mitigate the effects of global warming. However this ‘sink’ has not been stable over the recent past and there is therefore a need to measure it in near real time with higher confidence than currently possible so that appropriate policy measures can be developed and implemented in response to any change. We have a wide array of tools including satellites, ship based and autonomous (gliders, moored, floats and surface vehicles) measuring systems which together with the associated data infrastructure can demonstrably come together to deliver this vision. These have largely been developed under short-term funding streams and, as a consequence do not currently deliver the robust, near real time, sustainable estimate of ocean C uptake that we believe is necessary to support international climate negotiations and the development of adaptation/mitigation strategies. We are currently developing a blueprint for the ‘Integrated Ocean Carbon Observing System’ which we believe will be as necessary for reliably forecasting climate over the next 5-10 years as meteorological observations currently are for forecasting weather over the next 5-10 days. In this contribution we will describe the key elements of this blueprint and outline a timeline for assembling them together to deliver an annual near realtime databased estimate of ocean carbon uptake to the annual COP in support of international climate negotiations.

Poster presentations in session 8

Vulnerability of intertidal seagrass patches from fungal diseases from the coast of South Andaman, India

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The seagrass meadows are considered to be as one of the "blue carbon" habitats and in supporting biodiversity and key ecosystem functions. These habitats are vulnerable to climate change impact and further from non-climate impacts such as drainage and coastal settlements. Such instances have caused frequent die-off events of these seagrass patches. These non-climatic human pressures on seagrass ecosystems have caused the associated faunal composition to drastically change. The present study is aimed to monitor the diversity of epiphytic and endophytic fungi from the intertidal seagrass patches from two distinct habitats in terms of anthropogenic activities from the coast of South Andaman, India. The selected sites are variable in terms of stress due to fishing, tourism, sewage and other shipboard activities. The study tries to identify the variability of microfungi from the seagrass from the selected stations on monthly basis for a period of 13 months (February 2019-March 2020). The isolation of these fungi were performed using the common microbiology isolation methods. The species isolated were further characterized and identified using molecular methods. The occurrence of plant pathogenic, environmental contaminates and other non-pathogenic fungi isolated were statistically interpreted to understand the spectrum of diversity of fungus associated with these seagrass patches. This study aims to majorly support the goal of propagation of seagrass beds along the coastal waters where ever possible as per ICRZ Notification 2019.

Two decades of carbon, water and energy fluxes from a mediterranean pine forest: San Rossore

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The pine forest of San Rossore, near the west coast of Tuscany in central Italy, is a perfect candidate to study the carbon, water and energy exchange through the lenses of inter-annual variability. The length of the time series of carbon, water and energy exchange measurements from this Mediterranean forest turned 20 years in 2019 and it is still running. Two species of the same genus, i.e. Pinus, with similar ecophysiological traits and located in the same area, being distant only few hundred meters each other, have been sequentially monitored. The measuring system, following an insect outbreak and the consequent clear cut in the initial study area dominated by Pinus pinaster Ait., has been moved in 2013 to a new stand dominated by Pinus pinea L., a species that has been significantly less impacted than the initial one by the outbreak. In this study we i) quantitatively estimate if the two subseries can be meaningfully compared and eventually merged and ii) present an overview of the trends of some ecological parameters over the period 1999-2019. Preliminary results indicate similarity of carbon and energy fluxes for the two pine species, both for half-hourly measured values of Net Ecosystem Exchange (NEE), Latent Heat (LE) and Sensible Heat (H), as well for half-hourly and daily modelled Gross Primary Production (GPP) and Ecosystem Respiration (Reco): as an example the light NEE response curves

obtained from seven years of data above the two forests for spring and summer periods, are characterized by very close estimates of the two parameters α and GPPsat (slope and GPP at saturation), whose relative differences are below the 3% threshold in three out of four cases. While the annual budgets of individual quantities like NEE, GPP, Reco, LE and H, show significant interannual variations and slightly pronounced differences between the two stands, the ratios of quantities related to the whole ecosystem efficiency, like e.g. Reco/GPP and evaporative fraction (LE / (H + LE)), are instead substantially constant throughout the decades for the two species, respectively lying around 0.8 and 0.6.

Hydrological functioning of irrigated maize crops in southwest France using Eddy Covariance measurements and a land surface model

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This study aims to analyze the main components of the energy and hydric budgets of irrigated maize crop as the major summer crop in South-West France. To this objective, the ISBA-A-gs model within the most recent version (v8.1) of the SURFEX modeling platform (SURFace EXternalisEe) is run over six maize cycles including the drought of 2019. More specifically, the objective of this work entailed the assessment of the SURFEX model and the evaluation of the soil-water components. In addition, the composite configuration of ISBA-A-gs is compared to the Multi Energy Balance (MEB) version. The objective of this study entailed the assessment of the SURFEX model and the evaluation of the soil-water components. This performance assessment was carried out over the Lamasquere site (43.48ºN, 1.249ºE) using a unique database of continuously observed sensible (H) and latent heat fluxes (LE) estimated by an Eddy Covariance system, measurements of net radiation (Rn), ground heat flux (G), plant transpiration with sap flow sensors, meteorological variables, and several vegetation characteristics. The seasonal dynamics of the convective fluxes were properly reproduced by both configurations with an R^2 ranging from 0.5 to 0.86, and a root mean square error between 20 and 48 Wm^{-2}. Nevertheless, statistical metrics show that H was better predicted by MEB with R^2 =0.80 in comparison to ISBA (R^2=0.73). However, the difference between the RMSE of ISBA and MEB during the well-developed stage of the plants for both H and LE does not exceed 8 Wm^{-2}. This implies that MEB does not have a significant advantage over ISBA as the soil and canopy were fully coupled with insignificant exposure of the background soil in a mature and homogeneous field. Furthermore, this study delved into the comparison of sap flow measurements with the transpiration simulated by ISBA and MEB. A good dynamics was reproduced by ISBA and MEB, although, MEB (R^2=0.75) provided a more realistic estimation of the vegetation transpiration by predicting based on the vegetation temperature, while ISBA (R^2=0.71) artificially partitioned LE based on the fraction cover and computed 'false' vegetation transpiration. Consequently, this study simulated the soil-water available during the growing season. Results indicated that plants' transpiration was ~233 mm on average, thus, 35% of total added water is lost by soil and vegetation evaporation with the exception of the year 2014 where 90% of water input was efficiently used by the plants. This provides insights into the possible implementation of optimal irrigation systems.

ICOS Integrated Carbon Observation System

Spatiotemporal variability of the surface water aragonite saturation state in the western Barents Sea

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Ongoing atlantification of the Barents Sea results in a shift towards a warmer and well-mixed ocean, that together with changes in the atmospheric forcing over the region, affect the oceanic absorption of CO_2 and consequently the saturation state of the calcium carbonate mineral form aragonite (ΩAr). Here historic underway fugacity of CO_2 (fCO_2) data (SOCATv2019) from 1995 to 2018 and new underway fCO_2 data from the research vessel Kronprins Haakon, together with ancillary sea surface temperature (SST) and sea surface salinity (SSS), are used to calculate the most extensive spatiotemporal distribution of the surface water ΩAr for the area so far. The determination of ΩAr is based on a derived total alkalinity (AT) using a new AT and SSS relationship for the western Barents Sea. Key drivers of the ΩAr variability are discussed in the light of ocean warming, changes in sea ice cover, and oceanic uptake of anthropogenic CO_2.

The global coordination of ecosystem functional properties

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Understanding the coordination of ecosystem functions across biomes and climate is still a major challenge that hampers our ability to properly predict biosphere response to climate change. Theories such as the leaf economics spectrum and the least cost investment strategy postulate that plants optimize the rate of investment in transpiration, photosynthetic capacity, and nitrogen (N) allocation dependent on the ratio of their costs to gain given their resources and environment. However, it is unclear ecosystem functions show coordinations as for leaf and plant traits.

We investigate the existence of a global spectrum of ecosystem functional properties, and analyze how state of the art terrestrial biosphere models reproduce the spectrum. To do so we used data of CO2, water and energy exchange for 203 sites (1484 site years) from the FLUXNET LaThuile and FLUXNET 2015 datasets with at least 3 years of data. For 86 sites, we were able to compile site information on canopy-scale measurements of foliar N concentration, maximum leaf area index, and stand age, from the literature.

We find evidence that a global spectrum of ecosystem functional properties exist, and that most of the variability (66.2%) is captured by three dimensions. The first dimension represents ecosystem productivity; the second the water availability gradient, and climate limitations to productivity; the third dimension reflects ecosystem respiration potential and carbon-use efficiency and is related to aridity and stand age and disturbance regimes. The first dimension of the spectrum is well captured by ecosystem models, while the second and the third dimensions are poorly reproduced. This might limit the ability of models to accurately predict the dynamic carbon, water and nutrient cycling in ecosystems in disturbed areas.

Finally, we show across ecosystems globally that leaf level theories can be in some cases translated to the ecosystem scale. As a main example we found an inverse relationship between photosynthetic N

and water use efficiency as postulated by the least cost investment theory across FLUXNET sites. However, this is possible only when scale emergent properties are accounted for (i.e. evaporation from soil and wet surfaces). This highlights that emerging biological patterns at ecosystem scale might be masked by other factors related to physical rather than biological responses.

Co-authors and FLUXNET PIs involved:

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Unseasonal vegetation seasonality in CMIP5 and CMIP6 simulations

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Vegetation seasonality is a key factor that modulating the surface energy, water, and carbon fluxes over mid- and high-latitude regions. Misrepresentation of the seasonal activity in climate models can lead to biases of surface mass and energy exchange and further uncertainties in climate prediction. Here we evaluate the simulation performance of vegetation seasonality of climate models that participating in Coupled Model Inter-comparison Project Phase 5 (CMIP5) and Phase 6 (CMIP6) to understand how well models describe the seasonal activity of temperate and boreal vegetation. We examined seasonal characteristics (annual mean, amplitude, and phase) in leaf area index (LAI) with the start and end of growing season using model outputs and satellite-observed data over the Northern extratropics from 1982 to 2014. CMIP5 and CMIP6 models tended to simulate larger annual means, weaker amplitudes, and delayed phases of LAI compared to the observation. Interestingly, most of the models represent the LAI phase delayed approximately one month compared to the satellite-based LAI, i.e., the lag of vegetation seasonality in ESMs, even in the latest CMIP6 models. The lag of LAI seasonality is mainly attributed to bad representation of the end of growing season that showing unrealistic distributions and severe delays more than 30 days compared to the observation. In addition, most of the ESMs cannot describe the responses of the start and end of growing season to seasonal warming as well as the climatological distributions of vegetation seasonality. Our results show that recent climate models have a weakness for describing seasonal changes in vegetation seasonality, especially for autumn phenology. It implies that phenology scheme of deciduous vegetation in climate models should be improved for better representation of vegetation seasonality and further its interaction with climate system.

Can we sense plant rooting depth from above?

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The evolution of evapotranspiration and ecosystem productivity during rain-free periods reflects sensitivity of leaf-level processes to droughts and the total rooting zone water storage capacity. Using eddy covariance measurements, we quantify the the efficiency by which radiation is used for ecosystem gross primary production (light use efficiency), and for transpiration (evaporative fraction), and derive their sensitivities to the increasing cumulative water deficit during rain-free periods. We hypothesise that these sensitivities are related to the total soil water holding capacity in the rooting zone, and that plants adjust their rooting depth to be optimally adapted to the local hydroclimatic conditions, quantified by extremes in the maximum cumulative water deficit experienced during rain-free periods. If confirmed, this would provide the basis for predicting global variations in plant rooting depth and vegetation sensitivity to droughts.

Session 9: Innovation and uncertainty in observation techniques, part 2

Oral presentations in session 9

Local-scale atmospheric inversion for the estimation of the location and rate of CH4 and CO2 controlled releases using mobile and fixed-point measurements

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One of the major challenges in mitigating greenhouse gas (GHG) emissions from oil and gas industrial facilities is the accurate detection, localization, and quantification of fugitive leaks in a timely manner. Various atmospheric inversion techniques based on atmospheric GHG concentration measurements collected by stationary or/and mobile sensors and local-scale atmospheric dispersion models have been developed to provide such a monitoring of the emissions from industrial sites and facilities. Controlled release experiments where artificial sources are generated with chosen release rates at various locations provide efficient ways of evaluating the skill of atmospheric inversion frameworks. Two campaigns of methane (CH4) and carbon dioxide (CO2) controlled release experiments were held at TOTAL Anomaly Detection Initiatives (TADI) in Lacq, France in October 2018 (TADI-2018) and October 2019 (TADI-2019) to test different local scale atmospheric measurement and inverse modeling systems. The series of controlled releases covered a wide range of release rates (~0.1 to 200 gCH4/s and 0.2 to

200 gCO2/s) and varying release locations. The releases during the TADI-2018 campaign were brief (with a typical duration of 4 to 8 minutes, in order to test the reaction to emergency situation, e.g., when large CH4 release occur) while those during the TADI-2019 campaign lasted 25 to 75 minutes. We participated to both campaigns, conducting both mobile and fixed point ~2-4 m height in situ atmospheric measurements simultaneously based on Picarro CRDS spectrometers, LGR MGGA, and LI-COR instruments. A vehicle driving downwind the area of controlled releases performed the mobile measurements. We developed and applied different inversion procedures to process separately the mobile and fixed-point measurements, but in both cases, it relies on a Gaussian dispersion model to simulate the atmospheric plume from the potential sources or the retro transport from the measurement locations back to potential source locations. The method used to process mobile measurements exploits the spread of the positions of individual plume cross-sections and the integrals of the gas mole fractions above the background within these plume cross-sections to infer the position and rate of the releases. The optimal position and rate minimize the misfits to the integrals and the departure from the measured wind of the effective wind directions from the source to the plume cross-sections. It provides estimates with a 20-30% average error for the CH4 and CO2 release rates during the TADI-2018 and TADI-2019 campaigns. The method used to process fixed-point measurements relies on the analysis of the variations of concentrations averaged over a series of temporal windows (with varying length) or over wind sectors. The comparison between modeled and observed set of average concentration informs the system about the source rate and locations. Results indicate an average error of ~25% on the release rate estimates. Overall, the average errors from both inversion frameworks are comparable and correspond to the best estimation precision found in past publications on site-scale inversions, even though we faced challenging emission and meteorological conditions during the TADI-2018 campaign. The presentation details these promising methods and results and discusses options for combining both types of measurements and inversion techniques and their potential.

Spatio-temporal kriging in estimating local methane sources from drone-based laser spectrometer measurements

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The most common approach to interpolate a geophysical field of interest to unknown locations is by applying ordinary kriging, which provides an estimate of the variable mean and its uncertainty. The theoretical formulation of ordinary kriging assumes that the variable of interest is spatially correlated following a Gaussian distribution. Furthermore, when samples are taken at different times, the stationarity of the geophysical field needs to be assumed. Since plume position and intensity vary with time in a correlated manner together with wind speed and direction, multiplying a CH_4 field obtained by ordinary kriging of the drone measurements combined with a mean vertical wind profile may lead to significant overestimation or underestimation of the true emission flux.

We test different modifications of the standard kriging method, such as moving-window kriging, cluster kriging, and quantile kriging, to account for the non-stationarity of the plume and the wind field. These modified kriging algorithms are applied not only to the drone-based methane observations but also to the wind measurements from an anemometer projected onto the drone path.

Methane concentrations are measured by a newly developed miniaturized high-precision quantum-cascade-laser based spectrometer that can be deployed on a drone. This allows quantifying CH_4 emission fluxes from diffusive facility-scale sources such as landfills and oil and gas production. Emission estimation is performed by applying a mass balance method where the drone is flown downwind of a given source perpendicular to the main wind direction at different altitudes above ground. Spatial gaps between altitudes are interpolated, and interpolated concentrations are multiplied by the cross-sectional area and the mean stream-wise wind profile to determine the total flux.

Here, we present an analysis of how well-known emissions from controlled release experiments can be quantified using these modified kriging algorithms. Furthermore, the sensitivity to different measurement configurations is discussed. We demonstrate the suitability of different quantification framework to investigate facility-scale sources and its flexibility to cope with complex situations which are not attainable with ordinary kriging methods.

Comparison of large eddy simulation of a point source methane plume in a slightly convective atmosphere with measurements from MEMO² campaign

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In order to constrain Greenhouse gas emissions, it is crucial to correctly measure and estimate the unknown sources. Methane is one of the largest contributors to the Europe's global warming impact and yet there are large discrepancies between emission inventories and estimations derived from the measurements. To address this issue, Methane goes Mobile - Measurements and Modeling (MEMO²) project was started. The focus of the project is to quantify local methane sources using different mobile platforms in combination with various modeling techniques. MEMO² project was part of the ROMEO (Romanian Methane Emissions from Oil and Gas) campaign, that took place in October 2019, where a large number of methane plumes from various oil and gas facilities were measured. During the campaign, a tracer release test was conducted in the vicinity of a ground point source and the transects of both plumes were measured simultaneously. The meteorological conditions were slightly convective with a low wind that changed direction during the day. Under these conditions the plume shows large meandering behavior making the measurements and source strength estimation challenging.

We have performed a large eddy simulation (LES) study of a plume released from a ground level point source into a flow over flat terrain with meteorological conditions set up according to the conditions present during the measurements. In order to simulate the meteorological conditions correctly, the simulation was nudged with the vertical profiles of wind components, temperature and specific humidity for the given location taken from ERA5. We studied the plume motions under these conditions and compared them to the plume transects from both the unknown source and the tracer gas.

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Use of the unmanned surface vehicle Saildrone to validate Fixed Ocean Stations - the ATL2MED mission

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In October 2019, two unmanned Saildrones equipped with oceanographic and meteorological sensors were launched from the Canary Islands, with the aim to sail the distance from Cape Verde in the Atlantic Ocean to Trieste (Italy) in the northern Mediterranean Sea. This mission - ATL2MED - was sponsored by the US company PEAK6 Invest, and lasted for more than 7 months. ATL2MED had two main objectives: 1) to study eddies in the Canary Current upwelling system off West Africa and 2) to validate carbon measurements from Fixed Ocean Stations along the route.

Here, we will give a taste of the carbon measurements in different ocean areas and we will show the first results from the validation effort for Fixed Ocean Stations, which included the ICOS stations CVOO in the Atlantic Ocean, W1M3A in the western Mediterranean Sea, and E2M3A, Paloma and Miramare in the Adriatic Sea, and the non-ICOS stations ESTOC in the Atlantic Ocean and DYFAMED in the western Mediterranean.

The ATL2MED mission illustrates the potential of using unmanned surface vehicles for in-situ validation of remote ocean stations with respect to funding, manpower, time, and external challenges like the Corona crisis that have ravaged the world during the last year.

Surface water CO_2 measurements in the North Atlantic Ocean: optimize methodologies and analytical procedures.

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High quality in situ observations of surface CO_2 concentrations are essential in order to increase the robustness of CO_2 flux estimates and the statistical analyses that underpin them. Various efforts - ranging from centralized EU Research Infrastructures (e.g. ICOS, EMSO, EuroARGO) to scientific community driven ones such as the Surface Ocean Carbon Atlas (SOCAT) - are attempting to fill in spatial and temporal data gaps with high quality observations of all necessary variables (fCO_2, Sea Surface Temperature, Salinity, Nutrients, etc.). Development of new technologies and optimization of methodologies is also critical to further improve data quality and reduce the uncertainties of derived products (i.e. fluxes).

Within this spirit and endorsed by ICOS, the UK's National Oceanography Centre (NOC) and the Flanders Marine Institute (VLIZ), both members of ICOS, have collaborated on two open ocean cruises in the North Atlantic in order to perform continuous surface seawater CO_2 and total alkalinity (TA) observations. DY103 on RRS Discovery at the PAP-SO time series site (ICOS and EMSO station, https://projects.noc.ac.uk/pap/) in June – July 2019, and JC191 on RRS James Cook, a GO-SHIP hydrographic cruise along 24.5°N from January until March 2020.

The DY103 cruise was setup as an inter-comparison exercise for equipment, methodologies and best practices of measuring and analyzing carbon parameters. During the cruise, different systems for surface water CO_2 and TA were installed on the underway water supply of the RSS Discovery. These systems ranged from custom made surface water CO_2 system (VLIZ equilibrator with Picarro G2201-i system), commercial sensors (Contros HydroC-CO2 FT, Pro-Oceanus CO2PRP) and also novel microfluidic systems by NOCs OTE group. Discrete samples were collected from the underway water supply and the CTD rosette Niskin bottles for dissolved inorganic carbon, TA, pH and nutrients. The discrete samples were analyzed in different laboratories both at sea and on land. There are differences between results from the various sensors/ equipment, as well as the discrete samples. During the second cruise (GO-Ship, JC191) systems were installed on the RSS James Cook to measure pCO_2 (VLIZ equilibrator with Picarro G2201-i system and HydroC-CO2 FT) and TA (Contros HydroFIA-TA) continuously. Additional carbon parameters were analyzed in discrete samples from 145 stations as well as from the underway water supply. Sea surface pCO_2 concentrations varied between 345 and 400 µatm, and showed differences between the western and eastern part of the transect.

This work will focus on the setups, equipment and methodologies that were used and identify the points that will allow further optimization of the sampling, analytical and methodological procedures in order to reduce the data uncertainties and consequently the products.

Poster presentations in session 9

Quantifying methane emissions from coal mining ventilation shafts using a small Unmanned Aerial Vehicle (UAV)- based system

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Atmospheric methane (CH4) is the second most abundant anthropogenic greenhouse gas (GHG) after carbon dioxide (CO2), with the globally averaged mole fraction of 1859 ± 2 [ppb] in 2017, more than 2.5 times pre-industrial levels. A strong contributor (∼447 kiloton CH4 in 2017) to the annual European CH4 emissions comes from the black coal (anthracite) mines in the upper Silesia coal basin, Poland, where large quantities of CH4 are emitted to the atmosphere via ventilation shafts of underground coal mines. However, atmospheric emissions of methane from coal mines are poorly characterized, as they are dispersed over large areas and continue even after a mine's closure. As part of the Carbon Dioxide and Methane mission (CoMet) 0.5, a study of the upper Silesia coal basin's regional CH4 emissions took place in August 2017. We flew a recently developed active AirCore system aboard an unmanned aerial vehicle (UAV) to obtain CH4 mole fractions downwind of a single coal mining ventilation shaft. In addition to CH4 mole fraction measurements, we also measured CO2, CO, atmospheric temperature, pressure, and relative humidity. Wind-speed and wind-direction measurements were made using balloon-borne radiosonde. Fifteen UAV flights were performed flying perpendicular to the wind direction at several altitude levels, to effectively build a 'curtain' of CH4 mole fractions in a two-dimensional plane at a distance between 150 and 350 [m] downwind of a single ventilation shaft. Our estimate of the CH4 emission rates from the sampled shaft ranges from 5.3 to 17.6 [kt/year] using a mass balance approach,

and between 4.9 to 11.2 [kt/year] using an inverse Gaussian method. The average difference between the mass balance and Gaussian inversion approach was 1.5 [kt/year]. Using a high correlation between CO2 and CH4, the CO2 flux was estimated to be between 2.4 - 7.8 [kt/year].

High accuracy position tracking of drone flights with low-cost RTK-GPS

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Consumer grade drones rely on simple geopositioning (GPS) systems, similar to those found in other utilities, such as cameras and mobile phones. This information, combined with measurements of atmospheric pressure, is then used to obtain the coordinates defining the drone position. However, for applications, such as plume mapping or emission measurements, the accuracy of about 0.5 m is not satisfactory, especially with respect to height, where even larger drifts may occur.

Alternatively, real-time kinematic (RTK) positioning can be employed to account for, e.g., clock-timing errors and ionospheric effects. RTK-GPS relies on a stationary GPS, called the base station, which provides a correction function that allows obtaining an accuracy of a few centimeters. Commercial RTK-GPS upgrades are only available for certain drones, they are not compatible with all electronic interfaces, and their high cost reflects the exclusive use for professional drone applications.

We addressed this situation by applying and validating a low-cost RTK-GPS board (Spark-Fun) equipped with a high-accuracy NEO M8P-2 chip. This chip is capable of RTK as well as outputting raw GPS data for post-processing. The board has a small form factor and is easy to setup. One board, ""rover"", is integrated with the data acquisition of our drone-based methane spectrometer, while the other board is deployed in a stand-alone, battery-powered base station. Post-processing with RTKLIB, an open source program package for GNSS positioning, allows retrieval of the corrected coordinates. This approach provides positioning accuracies in the cm range. All components are open-source and can be ap-plied more generally to any field measurements, which require accurate GPS coordinates.

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Quantification of methane emission from oil and gas wells using Other Test Method 33a during ROMEO campaign

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The ROMEO project focusses on measuring and quantifying methane emissions from the extraction and exploitation of oil and natural gas in Romania. The main campaign took place in October 2019 and covered the southern part of the country around the cities Bucharest, Ploesti, Pitesti and Craiova. About

70 people participated in the campaign and formed 11 research teams. Romania is the country in the EU, with the highest reported CH4 emissions from the oil and gas sector. The ROMEO campaign aimed to quantify methane emissions from fossil fuels in Romania using various measurement techniques and devices. During the campaign, mobile measurements from vehicles, drone flights and also aircraft flights were used. One of the mobile measurement methods was the EPA Other Test Method 33a (OTM-33a). This method was used to quantify emissions from point sources of oil and natural gas wells that had beforehand been screened. The main problem during our campaign was the variability of wind direction and velocity and several days of extremely low wind velocity. These unfavourable weather conditions complicated the quantification of methane emitters at the beginning of the campaign. In total approximately 120 individual oil and gas wells were quantified using OTM-33a (by three teams), while the total number of screened facilities was nearly 1500. The estimated emission using OTM-33a varies between 0.01 to 100 g CH4 / s, while when maximum methane concentrations reached up to 1500ppm. Not all OTM-33a quantifications were accepted due to non-compliance, so approximately 60-70% of all OTM-33a were accepted.

MEMO²: MEthane goes MObile – MEasurements and Modelling

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Reaching the targets of the Paris Agreement requires massive reductions of greenhouse gas emissions. CH_4 emissions are a major contributor to Europe's global warming impact and emissions are not well quantified yet. There are significant discrepancies between official inventories of emissions and estimates derived from direct atmospheric measurement. Effective emission reduction can only be achieved if sources are properly quantified, and mitigation efforts are verified. New advanced combinations of measurement and modelling are needed to archive such quantification.

MEMO² is a European Training Network with more than 20 collaborators from 7 countries. It is a 4-years project and will contribute to the targets of the EU with a focus on methane (CH_4). The project will bridge the gap between large-scale scientific estimates from in situ monitoring programs and the 'bottom-up' estimates of emissions from local sources that are used in the national reporting by I) developing new and advanced mobile methane (CH_4) measurements tools and networks, II) isotopic source identification, and III) modelling at different scales. Within the project qualified scientists will be educated in the use and implementation of interdisciplinary knowledge and techniques that are essential to meet and verify emission reduction goals. MEMO² facilitates intensive collaboration between the largely academic greenhouse gas monitoring community and non-academic partners who are responsible for evaluating and reporting greenhouse gas emissions to policy makers.

We will present the project, its objectives and the results so far to foster collaboration and scientific exchange.

Session 10: Fluxes at the land-ocean-atmosphere continuum, part 2

Oral presentations in session 10

A Carbon-budget for the north-west European shelf - limitations and uncertainties

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The ocean is globally responsible for the annual uptake of a quarter of anthropogenic CO_2 emissions with the potential for long term storage in sediments and deep water. We have used a dataset of 300k marine fCO_2 observations to calculate the influx of CO2 from the atmosphere over the NW European shelf in 2015 and presented this in the context of a C-budget (https://www.nature.com/articles/s41598-019-56363-5). We found that: a) the annual air to sea influx in 2015 was dominated by winter storminess, b) the air to sea and shelf to open ocean fluxes were the largest C-input and output terms respectively and c) terrestrial fluxes of organic and inorganic C, largely outgassed in estuaries and the coastal zone without contributing to off-shelf transport. Here, we expand on the limitations and uncertainties of this approach and the possible role of ICOS and the wider community in constraining: a) C-fluxes from land, b) estuarine/coastal mineralization and outgassing and c) C-burial in sediments. These terms carry the largest uncertainties in our budget and are critical in our understanding of the climate-regulation service

that the NW European shelf provides. The fate of carbon in the shelf to open ocean flux term is critical in this respect, but poorly understood.

Carbon on the northwest European shelf: contemporary budget and future influences

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A carbon budget for the northwest European continental shelf seas (NWES) was synthesized using available estimates for coastal, pelagic and benthic carbon stocks and flows. Key uncertainties were identified and the effect of future impacts on the carbon budget were assessed. The water of the shelf seas contains between 210 and 230 Tmol of carbon and absorbs between 1.3 and 3.3 Tmol from the atmosphere annually. Offshelf transport and burial in the sediments account for 60–100 and 0–40% of carbon outputs from the NWES, respectively. Both of these fluxes remain poorly constrained by observations and resolving their magnitudes and relative importance is a key research priority. Pelagic and benthic carbon stocks are dominated by inorganic carbon. Shelf sediments contain the largest stock of carbon, with between 520 and 1600 Tmol stored in the top 0.1 m of the sea bed. Coastal habitats such as salt marshes and mud flats contain large amounts of carbon per unit area but their total carbon stocks are small compared to pelagic and benthic stocks due to their smaller spatial extent. The large pelagic stock of carbon will continue to increase due to the rising concentration of atmospheric CO2, with associated pH decrease. Pelagic carbon stocks and flows are also likely to be significantly affected by increasing acidity and temperature, and circulation changes but the net impact is uncertain. Benthic carbon stocks will be affected by increasing temperature and acidity, and decreasing oxygen concentrations, although the net impact of these interrelated changes on carbon stocks is uncertain and a major knowledge gap. The impact of bottom trawling on benthic carbon stocks is unique amongst the impacts we consider in that it is widespread and also directly manageable, although its net effect on the carbon budget is uncertain. Coastal habitats are vulnerable to sea level rise and are strongly impacted by management decisions.

Local, national and regional actions have the potential to protect or enhance carbon storage, but ultimately global governance, via controls on emissions, has the greatest potential to influence the long-term fate of carbon stocks in the northwestern European continental shelf.

Quantifying the fluxes of inorganic carbon and alkalinity through UK estuaries

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The contribution of estuaries to the global carbon cycle is poorly quantified. There are two key challenges in improving estimates of inorganic carbon flux through estuaries. Firstly, sampling several estuaries at a sufficient resolution to determine seasonal changes is logistically difficult. Secondly, there is no consensus on the most appropriate measurement and calculation techniques for carbonate system variables across a large salinity range (i.e. 0 to 35). To help address these challenges, we collected water samples from 14 inner estuaries across Great Britain from 2017-18 for the NERC-funded LOCATE (Land Ocean Carbon Transfer) programme. We analysed these samples for dissolved inorganic carbon (DIC) and total alkalinity (AT), adapting existing seawater AT measurement and calculation techniques to better suit the large salinity range. Our data show that the carbonate chemistry of estuaries is strongly linked to the upper catchment bedrock lithology. In particular, the presence of limestone seems to cause the alkalinity of low-salinity water samples to increase from approximately 0 to 5000 μmol kg^{-1}, driving a similar-magnitude increase in DIC. There is strong seasonality in many estuaries, sometimes sufficient to switch from a negative correlation between salinity and DIC/AT in the spring to a positive correlation in the autumn and winter. We quantify for the first time the fluxes of inorganic carbon and alkalinity through the sampled estuaries and consider their importance in the context of the overall carbon budget of the surrounding shelf seas.

Greenhouse gas concentrations and fluxes from seven UK estuaries

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Estuaries act as an intermediary between fresh and saline waters, and present a unique biogeochemical environment where terrigenous carbon can be processed. Emission as greenhouse gas (GHG) is one potential fate for this carbon, and methane (CH4) emissions from estuaries have previously been found to be significant. However, controls of GHG production in estuaries remain poorly understood. Here we present dissolved GHG data collected as part of the NERC-funded LOCATE programme. Axial surface water sampling was undertaken on a quarterly basis from July 2017 to April 2018 across seven UK estuaries. GHG concentrations were highly variable both spatially and temporally, with CH4 concentrations ranging from 3.6 to 4262 nM. On average, highest GHG concentrations were detected at lower salinities (0-5 psu), suggesting that inner estuarine environments are emissions hotspots. Concentrations of CH4 were positively correlated with PO43- concentrations (r2: 0.32), confirming that nutrients are a driver of estuarine GHG production. Using data from the Dart and Tamar estuaries, we upscaled to estimate a potential national CH4 flux from estuaries: 2.39 x 109 g yr-1. This is an important source, particularly given the high global warming potential of CH4, and thus warrants inclusion in both national and global carbon cycle budgets.

Estimations of air-sea carbon flux based on in situ CO_2 measurements at the Belgian Continental Shelf

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Observing the balance of greenhouse gases is an important way to keep track of global change (Steinhoff et al., 2019). One important element in this balance is the atmosphere-water exchange of CO_2 in the ocean. The air-sea CO_2 flux provides insight in how much CO_2 is incorporated in the marine environment (i.e. the sea being a sink for atmospheric CO_2) or emitted by the marine environment (i.e. the sea being a source).

As of 2013, as part of the European research infrastructure "Integrated Carbon Observation System" (ICOS), Flanders Marine Institute (VLIZ) measures the pCO_2 in the seawater surface layer of the Belgian Continental Shelf and the atmospheric CO_2 concentration at 3 m above sea level. In this study, we used observations of pCO_2 collected at the ICOS Station BE-FOS-VLIZ Thornton Buoy from February until December 2018. The station is located at the Thornton bank, a sandbank approximately 30 km seawards from the coast near Zeebrugge. We calculated the air-sea carbon fluxes according to the wind driven turbulence diffusivity model of Nightingale (2000).

In order to evaluate the quality of the atmospheric CO_2 concentration data from the buoy, we have compared them against data from the ICOS ATM Stations in Cabauw (207m; Frumau et al., 2020), Tacolneston (185m; O'Doherty et al., 2020) and Mace Head (24m; Delmotte et al., 2020). These stations are situated on land relatively close to the coast. The atmospheric CO_2 data of the Thornton Buoy is significantly different from the CO_2 from the other stations. Thornton Buoy's atmospheric CO_2 concentration is on average 2.37% lower than at the other ICOS monitoring stations, which could indicate a bias. A possible explanation could be that our measurements were not normalized for water vapor content. This will be further examined. Nevertheless, similar temporal trends were observed between the atmospheric CO_2 data of the Thornton Buoy and the ICOS ATM Stations.

Our results show a clear seasonality of air-sea carbon flux at the Thornton Buoy, with the sea being a carbon sink from February until June switching to a carbon source from July until December. This seasonality is also reported in Gypens et al. (2004 and 2011) and is hypothesized to be driven by temperature, biological processes and the impact of the freshwater plume of the Scheldt river (Gypens et al., 2011). We calculated that the sink was largest in April, while in August, the source was at its maximum. Increasing the amount of pCO_2 observations with the RV Simon Stevin will allow us to further explore the spatial variability of the air-sea carbon flux at the Belgian Continental Shelf.

Poster presentations in session 10

Using ICOS flux data to estimate prior uncertainty and its impact on simulated variability of atmospheric CO2

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The CO2 Human Emission (CHE) project has produced a global CO2, CH4 and CO nature run simulation at 9km resolution for 2015 based on the Copernicus Atmosphere Monitoring Service (CAMS) forecasting system which is part of the Integrated Forecasting System (IFS) at ECMWF. The aim of the CHE nature run is to produce realistic atmospheric tracer variability and to provide a reference for Observing System Simulation Experiments. The simulations include tagged tracers that estimate the contribution of the biogenic and anthropogenic fluxes in the simulated atmospheric variability. We find that the largest source of errors in the atmospheric CO2 variability comes from the online biogenic fluxes in the land surface model (CTESSEL). However, with the evaluation of atmospheric CO2 it is difficult to separate errors coming from transport and surface fluxes. The ICOS ecosystem data will be used to evaluate the modelled biogenic flux uncertainty at different temporal scales from sub-diurnal to synoptic to seasonal. The modelled fluxes will also be compared to other flux products, such as FLUXCOM and the CAMS CO2 inversion product, in order to assess the errors in the flux gradients and the large-scale budgets of the biogenic fluxes. The ultimate goal of this evaluation is to understand the source of biogenic flux errors so that we can improve the underlying biogenic model, as well as to quantify the uncertainty of prior fluxes for future atmospheric inversions based on the IFS.

Storms and sea-ice processes in the high Arctic Ocean enhance wintertime ocean CO_2 uptake

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The ice cover in the Arctic Ocean has decreased during the last decades, manifested particularly as an extensive transition from thicker multiyear ice to thinner first-year ice. As the summer sea-ice cover is decreasing, larger areas with open water will be exposed to the atmosphere. In winter, the sea ice partly prevents direct CO_2 exchange between ocean and atmosphere. However, frequently occurring storms in winter and spring cause open leads and breakup of the ice sheet, increasing the potential for direct air-sea CO_2 exchange. During storm events, vertical mixing brings enriched CO_2 from sub-surface water to the surface. In addition, sea-ice processes impact the under-ice water. This will have implications for the marine CO_2 system and ocean acidification. Data on Arctic under-ice water CO_2 fugacity (fCO_2) was collected from January to June 2015 during the Norwegian young sea ICE (N-ICE2015) expedition, covering the deep Nansen Basin, the slopes north of Svalbard, and the Yermak Plateau. Impacts of sea-ice biogeochemical processes on the surface-water fCO_2 were estimated. Depending strongly on the open-water fractions and storm events, the ocean CO_2 sink varied between 0.3 and 86 mmol C m^{-2} d^{-1}. The observed under-ice fCO_2 ranged between 315 µatm (in February) and 153 µatm (in June), indicating that the surface water fCO_2 was undersaturated relative to the atmospheric fCO_2. In winter, the main drivers of the change in under-ice water fCO_2 were dissolution of $CaCO_2$ (ikaite) and vertical mixing. In June, in addition to these processes, primary production and sea-air CO_2 fluxes were important.

Evaluation of model-data mismatch errors in the CarboScope-Regional Inversion System

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With an increasing network of atmospheric stations that produce a constant 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 inversion consists of Lagrangian mesoscale transport from STILT, prior fluxes from the diagnostic VPRM biosphere model, and anthropogenic emissions from a combination of EDGAR v4.3 with the annually updated BP statistical report. Regional ocean fluxes were derived from the CarboScope ocean flux product based on SOCATv2019 data. The inversion uses atmospheric observations from 44 stations to infer biosphere-atmosphere exchange. The regional 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 (i.e. the state space).

One of the critical parameters is the assumed uncertainty of the observations, and the major contribution to this is the model-data mismatch error, or representation error. Within CarboScope-Regional, this model-data mismatch error is specified differently for different station types, such as tall towers, mountain or coastal stations, etc. To evaluate the validity and appropriateness of these assumed uncertainties, a leave-one-out cross-validation is applied for a single year, using all stations except one for the inversion, and comparing posterior concentrations predicted for the omitted station with the observed concentrations. Results of this cross-validation will be presented separately for the different station types, and will be used to evaluate the magnitude of the assumed model-data mismatch errors.

CongoFlux: the first flux tower of the Congo Basin Forest

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Central African forests are poorly studied yet an important component in the global greenhouse gas balance. As part of the European YPS project (Yangambi, pôle scientifique au service de l'homme et des forêts), Ghent University is scientifically responsible to set up the very first eddy covariance flux tower in the tropical forest of the Congo Basin in the UNESCO MAB of Yangambi, close to Kisangani (Democratic Republic of the Congo). Once operative, this tower will deliver the very first accurate and continuous data of atmosphere-ecosystem exchanges of greenhouse gasses including CO2, N2O, CH4 and H2O of the Congo Basin forest.

Do climate-driven changes in tree hydraulics and osmolality affect VOC and NOx emissions from silver birches?

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Higher humidity, which is predicted for northern latitudes can cause significant changes in forest growth and function. Increase in air humidity at FAHM experimental site, Estonia, has shown to affect tree water status and increases the levels of antioxidants and accumulation of carbohydrates in leaves. Such changes suggest potentially higher volatile organic compound (VOC) emissions from trees. Changed nutrient acquisition due to higher humidity on the other hand might affect nitric oxide (NOx emission) from forests. However, the effect of higher air humidity and changed water status of trees on reactive volatile compound emissions are rarely studied in field.

Our studies show the dynamics of VOC emissions from birch shoots grown at more humid versus ambient conditions, suggesting, that differences in soil moisture and atmospheric humidity can produce variations both in total VOC emission from canopy but also alters the abundance of different VOC compounds at different times of growing season. We also demonstrate the effect of leaf water status and osmotic potential on emissions of most abundant VOC-s and NOx emitted from birches.

Using land-based stations for air-sea interaction studies, issues with land influence and non-stationarity

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In-situ measurements representing the marine atmosphere are taken at ships, buoys or stationary moorings, or on land-based towers. By using fixed towers motion correction can be avoided and measurements can be taken over extended periods of time. One needs to make sure the measurements represents the sea area and evaluate the land influence at different scales on the fluxes, in addition there are indications that non-stationarity of the wind field over the sea significantly disrupts the equilibrium between the wind, stress, and wave fields, which potentially can alter the surface drag as well as heat and scalar fluxes.

Measured gas fluxes and turbulence properties from the land-based marine ICOS station Östergarnsholm have shown to well represent open sea marine conditions for specific wind direction intervals. Data from other sectors are usually discarded as they are disturbed by coastal zone. Data is defined according to the following categories:

1)Marine data representing open sea

2)Disturbed wave field resulting in physical properties different from open sea conditions and heterogeneity of water properties in the foot-print of the flux tower.

3)Mixed land/sea footprint of the tower, very heterogeneous conditions and a very active carbon production/consumption.

There are differences between the data for the different categories, and coastal processes influences carbon and heat fluxes (Rutgersson et al., 2020). Limited fetch conditions have an impact on the surface stress and the impact of non-stationarity on the stress and drag coefficient becomes important for wind speeds less than about 6 m s^{-1} (Mahrt et al., 2020) even for open sea conditions.

Quantifying and revisiting canopy stomatal conductance above the maritime pine FR-Bil ICOS station, France

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Stomatal conductance is one of the main physical parameters controlling transpirational ecosystem water loss. Canopy stomatal conductance (Gs) is regulated by soil water availability, but is also very sensitive to atmospheric water demand, i.e vapor pressure deficit (VPD). Different approaches have been performed to calculate and partition the control of water fluxes by canopy stomatal conductance within and above forest Ecosystems. Here we present experimental and modeling results from the maritime pine FR-Bil ICOS station (Salles, France) using different approaches to calculate Gs from:

1 - Penman-Monteith (PM) equation

a- PM inversion and eddy covariance - Due to the increase in ecosystem monitoring with flux tower. This approach is frequently used to assess canopy conductance (e.g Reichstein et al., 2002; Massman & Gentine, 2019). However PM inversion only gives a global conductance of the ecosystem, that includes the understory fluxes and therefore its conductance. To compute Gs from this approach several assumptions are required such that tree transpiration must be the dominant term of the latent heat flux (LE), a leaf area index greater than 2, turbulent conditions and others.

b- PM inversion and sap flow data (Granier et Loustau 1994) - this method uses PM inversion at the whole canopy layer scale. LE is measured through sap flow sensors (Granier 1987) and the radiative term is corrected with the foliage temperature. The focus on canopy alone allows to calculate directly Gs

2 - Water vapour transport equation

a- A simplified, but commonly used method (Monteith and Unsworth 1990) where transpiration is directly proportional to Gs times VPD; in this method the stomatal canopy conductance is directly calculated applying sap flow sensors to measure tree transpiration.

b- The integrated form of the transport equation is used with the foliage temperature being determined using an infra-red (IR) thermal camera.

We hypothesised that the last method may provide more meaningful values of Gs of the whole canopy, and be more useful for modelling canopy gas exchange through forest ecosystems. Moreover, this approach has fewer methodological constraints and may therefore be applied widely, e.g. in complex terrains (steep slope, discontinuous canopies, isolated trees or hedges etc.).

At this ICOS site, we tested this method with sap flow sensors installed at the base and top of the tree trunks, and in addition directly in branches, which is rarely done. We used a data set covering spring and summer 2020 to compare Gs values obtained from the methods (1.a) to (2.b) and illustrate their respective limitations and performances.

Our analysis is expected to reveal that the surface temperature quantification improved Gs determination and also its response to VPD, which has implications for the whole ecosystem response to future climate, in particular to the predicted increase in air temperature.

Session 11: Bridging remote sensing and in situ measurements of GHG and related observations, part 2

Oral presentations in session 11

Using satellite observations to detect and quantify concentrated methane emissions

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Satellite observations complement the existing ‘ground-based’ measurement networks for estimating methane emissions. The advantage of satellite observations is global coverage; the challenge, however, is achieving the required accuracy as satellites measure the total column of methane in the atmosphere while emissions occur at the surface. Much progress has been made in the past decade using satellite observations of methane, but the focus was mostly on large-scale variations in atmospheric methane. However, in recent times, with improving quality and availability of satellite data, the focus has shifted towards regional and even local scales. With the launch of the Dutch-ESA TROPOMI instrument in October 2017, a huge step forward was taken by combining high spatial resolution measurements (~5.5x7 km2) with daily global coverage. This has the potential to detect and quantify large emissions from fossil fuel (oil, gas, coal) and other point sources of methane.

This presentation will report on a few cases where observations from TROPOMI were used to identify various methane sources across the globe and to quantify their emissions. These sources can be persistent or transient sources, as well as local or regional sources. In addition, we have a collaboration with GHGSat where TROPOMI observations are used to ‘tip and cue’ GHGSat to detect and attribute methane emissions to specific facilities. GHGSat performs methane observations with limited coverage but very high spatial resolution (50 m x 50 m).

Towards greenhouse gas remote sensing evaluation using the AirCore atmospheric sampling system

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Carbon dioxide (CO2) and methane (CH4) are the two most important atmospheric greenhouse gases due to their high growth rate and relative impact on the earth's radiative balance, and accurately quantifying fluxes of these gases is crucial for predicting future climate. Satellites provide retrievals of whole or partial column weighted averages of these greenhouse gases at horizontal spatial scales unmatched by ground-based observing systems.

However, these remote sensing retrievals cannot be calibrated and sometimes contain large biases and uncertainties: both of which limit their overall potential for inferring surface fluxes and comparability to ground-based observing systems.

The AirCore is a patented, balloon-borne sampling system that collects whole air samples from the surface to the lower stratosphere (~30km) at better than 0.01 atm resolution in pressure altitude, and can provide a linkage between spaceborne and ground-based greenhouse gas observations through calibrated profiles of greenhouse gases and other long-lived tracers. We describe here efforts to improve the compatibility of remote sensing greenhouse gas retrievals -- and underlying biases in these retrievals -- through routine AirCore profiling. We report overall results of ground-based and satellite remote sensing retrieval evaluation of greenhouse and other trace gases at several Total Carbon Column Observing Network (TCCON) stations within the U.S. and Europe during several AirCore-based campaigns over the past three years. As many satellite bias corrections are based on global models, and TCCON retrievals and scaling rely on empirical stratospheric models, we also highlight efforts to confront these different models using the AirCore. Finally, we describe several advances made toward establishing an international AirCore network through collaboration with the Readiness of Integrated carbon observation system (ICOS) for Necessities of integrated Global Observations (RINGO) project and offer methods for routine, AirCore-based satellite evaluation in collaboration with the Collaborative Carbon Column Observing Network (COCCON).

Simulating CO_2 plumes from power plants at (sub-)kilometer-scale and consequences for satellite-based CO_2 emission monitoring

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The European Union's Copernicus programme is planning a monitoring capacity for anthropogenic CO_2 emissions. A central element of this capacity will be a constellation of satellites, the CO2M mission, with the capability to image CO_2 and NO_2 emission plumes of cities, power plants, and other large point sources at a resolution of approximately 2 km x 2 km. Together with ground-based observations, the satellites will monitor anthropogenic CO_2 emissions to support the signatory countries of the Paris Agreement, cities and industry in tracking progress towards their emission reduction targets.

However, reliable emission estimates from satellite observations of total column CO_2 will require supplementary atmospheric transport simulations. This raises the question of how well atmospheric transport models are able to simulate the spatio-temporal structure of CO_2 plumes emerging from large point sources such as power plants and large urban centers. To address this question, we present an analysis of high-resolution (1 km x 1 km) simulations of CO_2 plumes from two of Europe's largest coal-fired power plants: Belchatow (Poland) and Jänschwalde (Germany). Simulations were conducted with the COSMO-GHG model, a mesoscale numerical weather prediction model, extended for the simulation of atmospheric tracers. Simulated power plant plumes are evaluated against airborne in-situ and remote sensing observations collected during the Carbon Dioxide and Methane (CoMet) campaign in 2018. We analyze the influence of different model settings (vertical emission profiles, meteorological data assimilation, horizontal numerical diffusion, parameterization of turbulence) on the structure of the plumes in order to identify an optimal configuration. Furthermore, COSMO-GHG is evaluated against output from the large eddy simulation (LES) model EULAG. For the Belchatow case, the simulations reveal a pronounced turbulent behavior of the flow with meandering plumes and puff-like structures even at scales of several kilometers. This indicates that snapshots as provided by the satellites may strongly deviate from idealized Gaussian plumes and, hence, their quantitative assessment will require sophisticated atmospheric transport modelling. Although the comparison with the observations shows a good performance of COSMO-GHG in terms of magnitude and spatial variability of the plume, a perfect match of the plume's position cannot be expected due to the stochastic nature of the encountered turbulent flow. These results demonstrate the fundamental limitations of simulating such plumes and provide guidance for the development of a future data assimilation and emission estimation system.

Assessments of in situ and remotely sensed CO_2 observations in a Carbon Cycle Fossil Fuel Data Assimilation System to estimate fossil fuel emissions

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The Paris Agreement foresees to establish a transparency framework that builds upon inventory-based national greenhouse gas emission reports, complemented by independent emission estimates derived from atmospheric measurements through inverse modelling. The capability of such a Monitoring and Verification Support (MVS) capacity to constrain fossil fuel emissions to a sufficient extent has not yet been assessed. The CO_2 Monitoring Mission, planned as a constellation of satellites measuring column-integrated atmospheric CO_2 concentration (XCO_2), is expected to become a key component of an MVS capacity.

Here we provide an assessment of the potential of a Carbon Cycle Fossil Fuel Data Assimilation System using synthetic XCO_2 and other observations to constrain fossil fuel CO_2 emissions for an exemplary 1-week period in 2008. We find that the system can provide useful weekly estimates of country-scale fossil fuel emissions independent of national inventories. When extrapolated from the weekly to the annual scale, uncertainties in emissions are comparable to uncertainties in inventories, so that estimates from inventories and from the MVS capacity can be used for mutual verification.

We further demonstrate an alternative, synergistic mode of operation, which delivers a best emission estimate through assimilation of the inventory information as an additional data stream. We show the sensitivity of the results to the setup of the CCFFDAS and to various aspects of the data streams that are assimilated, including assessments of surface networks.

Poster presentations in session 11

Remote sensing and in situ measurements of greenhouse gases at Sodankylä, Finland

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Remote sensing measurements of greenhouse gases have been performed at Sodankylä since early 2009 using a Fourier Transform Spectrometer (FTS). The instrument records spectra of the sun in the near-infrared spectral region. From the spectra dry-air mole fractions of greenhouse gases are derived, including CO_2, CH_4 and N_2O. Our instrument participates in the Total Carbon Column Observing Network (TCCON). Here we present long-term observations of methane and carbon dioxide and comparisons with satellite borne measurements. We find good agreement between the ground-based FTS measurements and the collocated Greenhouse gases Observing SATellite (GOSAT) observations. We have also performed AirCore measurements at the TCCON site to study accuracy of the remote sensing retrievals. AirCore instrument has been flown on a meteorological balloon and more recently on a drone. The measured AirCore profiles have been combined with in situ tower measurements.

Evaluating time series of leaf chlorophyll content prediction from multispectral remote sensing data

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The leaf chlorophyll content is an essential pigment used by photosynthesis for the conversion of solar radiation into stored chemical energy. Accurate modelling of leaf chlorophyll content over a range of spatial and temporal scales is central to monitoring vegetation response to climatic and anthropogenic drivers. Satellite time-series observations, when combined with a quantitative approach using the radiative transfer model, can provide a unique opportunity for operational retrieval of chlorophyll. The retrieval of seasonal variation in chlorophyll, however, depends on the good temporal coverage of remote sensing images. A single remote sensing sensor is not capable of providing higher temporal resolution images due to the cloud cover. Recently, NASA has produced the Harmonized Landsat and Sentinel-2 (HLS) data by combining the surface reflectance data from two sensors onboard Landsat-8 and Sentinal-2 satellites to improve the temporal coverage. The HLS data, thus, provide an opportunity for chlorophyll retrieval to capture its adequate seasonal variability. The accuracy of time series of retrieved chlorophyll is essential to investigate using the field measurements. In this study, we investigate the potential of HLS data for the operational retrieval of seasonal variation in leaf chlorophyll content using the radiative transfer model. During the growing season in 2019 and 2020, a time series of chlorophyll will be retrieved for different ecosystems by optimizing the coupled canopy leaf radiative transfer model (leaf model PROSPECT5 + canopy model 4SAIL) against the top-of-canopy reflectance obtained from HLS data. The time series of retrieved chlorophyll content will be supported by extensive in-situ data collected in 2019 and 2020 for different forest ecosystems in the Czech Republic – floodplain mixed forest (2019), European beech (2020) and Norway spruce (2020). For all study sites, the following parameters are measured in different phenological stages, at least three times during the season: leaf chlorophyll content (non-destructive measurements using Force-A Dualex, Minolta SPAD, Multispeq 2,

CCM-300 and destructive laboratory analyses) and leaf-level optical properties measurements using integration sphere and leaf contact probe. For each site, 10-20 trees with a wide range of structures and species compositions (when available) are sampled to yield a high range of in-situ observed chlorophyll values. These, together with multi-temporal leaf sampling, will produce a representative database of leaf chlorophyll and optical properties for thorough validation of multi-temporal HLS chlorophyll retrievals using coupled canopy leaf radiative transfer model.

CH4 profile retrieval from ground-based FTIR near-infrared spectra

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The Total Carbon Column Observing Network (TCCON) column-averaged dry-air mole fraction of CH4 (XCH4) measurements have been widely used to validate satellite observations and to estimate model simulations. The GGG2014 code is the standard TCCON retrieval software used in performing a profile scaling retrieval. In order to obtain several vertical pieces of information in addition to the total column, in this study, the SFIT4 retrieval code is applied to retrieve the CH4 mole fraction vertical profile from the Fourier transform spectrometer (FTS) spectrum at several sites. The retrieval strategy of the CH4 profile retrieval from ground-based FTS near-infrared (NIR) spectra using the SFIT4 code (SFIT4NIR) is presented. The degree of freedom for signal (DOFS) of the SFIT4NIR retrieval is about 2.4, with two distinct pieces of information in the troposphere and in the stratosphere.

In this study, we compare the CH4 vertical profile from ground-based FTIR measurements with AirCore measurements during the Trainou campaign 2019. The difference between the remote sensing and in situ AirCore techniques are discussed.

Session 12: Budgets, trends, and controls of GHG and other atmospheric constituents, part 2

Oral presentations in session 12

Modelling seasonal cycle of atmospheric $\delta^{13}C\text{-}CH_4$ and their evaluations with $\delta^{13}C\text{-}CH_4$ observations

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The atmospheric burden of methane (CH_4) has more than doubled since the pre-industrial era. Currently the abundance of CH_4 in the atmosphere is well known, but the magnitude of emissions from different source sectors including natural and anthropogenic are uncertain. Most CH_4 source have process specific $\delta^{13}C-CH_4$ values, which can be used to broadly identify source sectors and to better understand the changes in atmospheric CH_4 abundance before and after 2006.

This study examines the seasonal cycle of atmospheric $\delta^{13}C-CH_4$ in recent decades using the TM5 atmospheric transport. TM5 is driven by ECMWF ERA-Interim meteorological fields, and uses pre-calculated OH-fields and reaction rates with Cl and O(1D) to account for the CH_4 sink processes in the atmosphere. TM5 is run at a 1ºx1º resolution over Europe and globally at 6ºx4º. Emissions for enteric fermentation and manure management, landfills and waste water treatment, rice cultivation, coal industry, oil and gas industry, and residential are taken from the EDGAR inventory. Natural emission for wetlands, peatlands and mineral soils, and soil sinks are taken from the LPX-Bern DYPTOP ecosystem model. Emissions for geological seeps including onshore hydrocarbon macro-seeps (including mud volcanoes), submarine (offshore) seeps, diffuse microseepage and geothermal manifestations are included. Emissions from fires (GFED v4), termites, and the ocean are also included. Several sensitivity analyses are carried out. The sensitivity analyses include simulations with and without seasonal cycles in the anthropogenic emission fields using different versions of EDGAR, and varying the source specific $\delta^{13}C-CH_4$ values, which are used to calculate $^{13}CH_4/CH_4$ emission ratios. The global observations of atmospheric CH4 and $\delta^{13}C-CH_4$, provided by NOAA's GMD, the INSTAAR and Royal Holloway, the University of London, are used for evaluation. Preliminary analysis have shown that EDGAR v5.0 provides the best seasonal cycle compared to other versions of the EDGAR inventory. We further analyse the effect of each source and sink, as a step towards CarbonTracker Europe-$\delta^{13}CH_4$ (CTE-$\delta^{13}CH_4$) data assimilation system to optimise CH_4 emissions by source category.

Validation and development of carbonyl sulfide biosphere exchange in the Simple Biosphere Model (SiB4)

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The uptake of carbonyl sulfide (COS) in plants is strongly dependent on stomatal conductance. The COS uptake is therefore strongly related to the photosynthetic uptake of CO_2 in plants. To be able to apply COS as a photosynthetic tracer requires an accurate representation of COS biosphere fluxes in models. The COS uptake by vegetation and soil is simulated by the Simple Biosphere Model (SiB4) but validation of these fluxes has previously not extended to different biomes. Overall, we find good agreement of simulated diurnal and seasonal cycles of COS ecosystem fluxes with flux observations made over grasslands, evergreen needleleaf forest and deciduous broadleaf forests over Europe and Northern America. We changed the prescribed COS mixing ratio from a fixed value to seasonally varying COS mixing ratio fields as retrieved from an inversion by the TM5-4DVAR model, in which COS exchange was recently implemented. The lower COS mixing ratios in the late growing season lowers the COS uptake rates, which further improves the comparison with observations. Furthermore, we updated the representation of soil COS uptake to account for uptake and release by the soil with existing soil COS models. Also, we explore the need to apply different CO_2 to COS uptake ratios to simulate fluxes of different plant functional types. The application of the COS biosphere fluxes in an inverse modelling study using TM5-4DVAR reveals an overestimation of uptake of COS over the tropics, which may be attributed to an overestimated COS biosphere sink in this region. These results highlight the importance to measure COS biosphere fluxes in the tropics for validation of model simulations and for closing the COS budget.

Resolving the diurnal cycle of $\Delta^{17}O$ in CO_2 at the ecosystem level: Simulations and observations at the mid-latitude pine forest Loobos

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The triple oxygen isotope signature $\Delta^{17}O$ in atmospheric CO_2 is a potential tracer for gross primary production (GPP). However, interpretation of $\Delta^{17}O$ in atmospheric CO_2 is complicated by the contributions from respired CO_2, isotopic exchange with soil and ocean water, and the release of CO_2 by fossil fuel combustion and biomass burning. Here we study $\Delta^{17}O$ in CO_2 at the ecosystem level, which is the domain that integrates the contributions from vegetation and soil to the atmospheric signal. We report for the first time an observed diurnal cycle of $\Delta^{17}O$ in CO_2, measured from air samples collected on 15-16 August 2019 at the mid-latitude pine forest Loobos (ICOS L2 ecosystem site). We also measured the isotopic signatures $\delta^{13}C$ and $\delta^{18}O$ in CO_2 close to the surface and above the canopy. To support the interpretation of the measurements and systematically analyze the interactions between meteorology and stable isotopologues, we used the mixed layer model CLASS. Also, we used the global atmospheric transport model TM5 to (1) quantify the contribution of different sources that affect $\Delta^{17}O$ in CO_2 at Loobos; and (2) extend our analysis of the diurnal cycle to the global scale. Our methodology demonstrates the added value of isotope measurements at ICOS ecosystem and tall-tower sites, and how to integrate meteorological and ecological observations from the canopy up to the atmospheric boundary layer.

COS-OCS: Carbonyl Sulfide, new ways of Observing the Climate System

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The future climate of the Earth strongly depends on the capacity of the global ecological system to sequester atmospheric CO_2, and on the abundance of stratospheric sulphate aerosols (SSA). These aerosols form a layer that resides at about 16 km altitude that, contrary to CO_2, has a cooling effect on the climate. These two climate-regulating mechanisms are intricately linked to an atmospheric gas that makes up only a tiny fraction of the Earth's atmosphere, carbonyl sulphide (COS). The COS-OCS project aims to fundamentally improve our limited understanding of the COS atmospheric budget which would therefore signal a major step forward in our ability to diagnose CO_2 uptake and SSA formation. The project also combines innovative modelling and measurements that will eventually allow breakthroughs in the coupled COS and CO_2 budgets, and unlock the potential of COS as a new climate diagnostic.

In this presentation, we will discuss the progress made during the last two years. Firstly, on the observational side, a measurement technique for the S-isotopologues of COS has been set-up. Samples from the lower stratosphere taken during the StratoClim campaign have been analysed. On top of that, in June 2019, four preliminary AirCore COS profile measurements were successfully conducted during a field campaign in Trainou, France by our Groningen team. We achieved high accuracy AirCore stratospheric COS measurements using a quantum cascade laser spectrometer (QCLS).

Second, several modelling activities will be reported. We have set-up a global inverse modelling framework for COS, in which NOAA COS samples are used to better constrain the global COS budget. We used observations made during HIPPO, NOAA aircraft profiles, and various sources of satellite data to evaluate the current global COS budget. We find that our optimised budget still under-estimates COS in the free atmosphere (> 2 km). Further steps will focus on the assimilation of satellite data in our inversion framework. On the scale of COS exchange with the biosphere, we have been employing the SIB4 biosphere model, which was evaluated using several sets of observations from Europe and from Harvard forest. Moreover, we are building an inverse modelling framework based on the boundary layer model CLASS (https://classmodel.github.io). This allows us to study the coupled exchange of COS and CO_2 with the biosphere.

Finally, we will outline the next steps we intend to take in measuring, modelling, and integrating models and observations to reduce the uncertainties in the global COS budget.

Inverse modelling of global carbonyl sulfide budget using TM5-4DVAR and model validation

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Carbonyl Sulfide (COS) has the potential to be used as a climate diagnostic due to its close coupling to the biospheric uptake of CO2 and its role in the formation of stratospheric aerosol. The current understanding of the COS budget, however, lacks of a COS source, which has previously been allocated to the ocean. We present a first attempt of global inverse modelling of COS within the 4-Dimensional variational data-assimilation system of the TM5 chemistry transport model (TM5-4DVAR). We focus on the uncertain global COS budget including COS production from its precursors carbon disulfide (CS2) and dimethyl sulfide (DMS). To this end, we implemented COS uptake by soil and vegetation from an updated biosphere model (SiB4), and new inventories for anthropogenic and biomass burning emissions. The model framework is capable of closing the COS budget by optimizing for missing emissions using NOAA observations in the period 2000--2012. The addition of 432 GgS/yr COS is required to obtain a good fit with NOAA observations. We found that the missing sources are likely located in the tropical regions, where also an overestimated biospheric sink cannot be ruled out. Moreover, high latitudes in the Northern Hemisphere require extra COS uptake or reduced emissions. HIPPO aircraft observations, NOAA airborne profiles, and several satellite data sources are used to evaluate the optimized model results. This evaluation indicates that COS in the free troposphere remains underestimated after optimization. Assimilation of HIPPO observations slightly improves this model bias, which implies that additional observations are urgently required to constrain sources and sinks of COS. We finally find that the draw-down of COS mole fractions over regions with an active biosphere may substantially lower the prior fluxes of the SiB4 biosphere model.

Poster presentations in session 12

Aerosol gradients and fluxes in a mixed oak-hornbeam forest

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The atmospheric aerosol is a major concern for human health. Trees were demonstrated to significantly influence the concentration of suspended aerosol since they can contribute both to the production of secondary aerosol and the removal of atmospheric aerosol.

In order to better understand the role played by the leaves in these processes size-resolved eddy covariance fluxes of fine (GMD between 0.1 μm and 1 μm) and ultrafine (GMD below 0.1 μm) aerosol were measured above the deciduous forest of Bosco Fontana in the Po Valley before and after leaf fall. To this purpose, an Electrical Low Pressure Impactor (ELPI+, DEKATI, FI) coupled with an ultrasonic anemometer was used.

The vertical distribution of different aerosol sizes above and within the forest was also assessed by means of a mini wide range aerosol spectrometer (GRIMM, D) and low cost sensors for PM 0.3 to 10 um (Plantower, CH).

Strong differences were observed in the behaviour of the single size-classes in presence and absence of leaves. The fine aerosol (GMD between 0.1 μm and 1 μm) was efficiently deposited on the leaf surfaces in the central part of the day during the leaf-on period, while an emission pattern was observed during the leaf-off period. The ultrafine aerosol (GMD below 0.1 μm), instead, was less influenced by the presence of leaves since it showed a net emission both with and without leaves.

Physical processes such as the diel variation of the Mixing Height and the different importance of impaction and interception over Brownian diffusion in the deposition of the various aerosol classes were accounted to interpret the observed fluxes and the aerosol distribution within the forest.

Coupled chemical transport model-Biosphere model for a better understanding of CO2 and COS budgets

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Carbonyl sulphide (COS) is a chemical compound that is present in our atmosphere at low abundance (~500 parts per trillion (ppt)). Especially, COS can be used as a proxy for global gross primary production (GPP) because uptake of COS by the biosphere proceeds similarly to CO2 uptake through plant stomata. Sources of COS include emissions from the ocean and anthropogenic activities (e.g., rayon production). Sinks of COS are the uptake by the biosphere and destruction in the stratosphere. The size of these sources and sinks are uncertain, and this uncertainty in the global COS budget limits the use of COS to constrain GPP. In this study, we will develop a link between the TM5 chemical transport model, and the Simple Biosphere model version 4 (SiB4). The TM5 model incorporates the latest inventories of sources and sinks of COS, and SiB4 is a dynamic vegetation model simulating COS exchange. Using this framework, we aim to identify and present: (i) characteristics of CO2 and COS uptake by vegetation and soil, (ii) feedbacks between atmosphere and biosphere, driven e.g., by the COS and CO2 mixing ratio changes. We will employ another biosphere model (Organising Carbon and Hydrology In Dynamic Ecosystems (ORCHIDEE)) for the comparison of biosphere COS flux and perform sensitivity-tests to investigate the effects of meteorology and mixing-ratio on the coupled model performance. This performance is assessed by a comparison of model simulations to observations will be presented.

Longterm N_2O observations at Lutjewad monitoring station: data quality, intercomparison, and trends

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We present 14 years of continuous observations of N_2O from Lutjewad monitoring station in the Netherlands (6.353° E, 53.404° N, 1 m asl) starting from May 2006 onwards. Air is sampled from a cryogenically dried ambient air stream collected at the top of the 60 m monitoring tower. The samples are analysed on a Agilent 6890N Gas Chromatograph (GC) equipped with a micro Electron Capture Detector (μ-ECD) at a rate of about 7 measurements per hour. The data between 2006 and 2012 have been recalculated and quality assessed following the InGOS project (Integrated non-CO_2 Greenhouse gas Observing System) QA/QC protocols aiming at correcting and harmonizing historical non-CO_2 data sets. For this period we obtained an overall measurement precision based on the Target tank reproducibility of <0.4 ppb for N_2O during optimal performance of the GC-system. About 40% of the hourly mean data points between 2006 and 2020 were flagged due to episodes of instrumental mal-performance, leaks affecting the air sampling and GC-system, as well as data gaps when the instrument was not running. We will discuss the observed long-term and seasonal trends as well as frequently occurring episodes of elevated N_2O concentrations related to regional sources. In the Spring of 2020 a new Picarro G5310 Cavity Ringdown Spectrometer (CRDS) for N_2O (and CO) was installed at Lutjewad station providing high resolution continuous data at a <0.1 ppb precision for N_2O. Both the GC and CRDS system will be running in parallel for several months sampling the same air stream and the first intercomparison results are presented here.

Forest-atmosphere exchange of reactive nitrogen in a low polluted mountain range - temporal dynamics and annual budgets

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The reactive forms of nitrogen such as ammonia (NH_3), nitrogen monoxide (NO), nitrogen dioxide (NO_2), nitric acid (HNO_3), nitrous acid (HONO), and ammonium nitrate (NH_4NO_3) are key components in biogeochemical and atmospheric cycles on earth. In contrast to elemental nitrogen, they heavily influence plant health and crop production. The sum of these compounds is often described as total reactive nitrogen (ΣNr). However, intensive supply of nitrogen through atmospheric deposition of NH_3, for example, may be harmful for natural ecosystems such as peatlands or forests. The additional amount of Nr will enhance the biosphere-atmosphere exchange of plants and can influence the carbon sequestration of ecosystems such as forests, although the effect of increasing nitrogen deposition on forest carbon sequestration has high uncertainty.

The Total Reactive Atmospheric Nitrogen Converter (TRANC) was used to convert the mentioned ΣNr compounds, except for nitrous oxide (N_2O) and molecular nitrogen (N_2), to nitrogen monoxide (NO). In combination with a fast-response chemiluminescence detector (CLD) the system allows measurements of ΣNr with a high sampling frequency. Due to a low detection limit and a response time of about 0.3 s the TRANC-CLD system can be used for flux calculation based on the eddy-covariance (EC) technique. The EC setup was operated above a low polluted, mixed forest in the Bavarian National Park in south-east Germany for 2.5 years. Additional instrumentation for measuring micrometeorological variables and observing concentrations of NOx and NH_3 was also installed at the site.

In this study, we analyze parameters, which favor nitrogen deposition into a mixed forest located in a remote low polluted area. We found that dry deposition of ΣNr is enhanced under elevated ambient ΣNr concentrations when conditions are dry, i.e., high temperatures, low humidity, and dry leaf surfaces. For calculating annual dry deposition budgets, gap-filling methods are needed to close gaps in flux time series. Therefore, we apply the deposition module DEPAC (DEPosition of Acidifying Compounds) with locally measured input variables, hereafter called DEPAC-1D, and a statistical method, the mean diurnal variation (MDV) method. Afterwards, ΣNr flux measurements and the site-specific modelling results of DEPAC-1D were compared to dry deposition fluxes using the deposition module DEPAC (DEPosition of Acidifying Compounds) within the chemical transport model LOTOS-EUROS (LOng Term Ozone Simulation – EURopean Operational Smog). In addition, the influence of land-use weighting in LOTOS-EUROS was examined. We further compare our results to ΣNr deposition estimates obtained with canopy budget techniques. Measured ΣNr dry deposition was 4.5 kg N ha^{-1} yr^{-1}, in close agreement with DEPAC-1D (5.2 kg N ha^{-1} yr^{-1}) and LOTOS-EUROS (5.2 kg N ha^{-1} yr^{-1} to 6.9 kg N ha^{-1} yr^{-1} depending on the weighting of land-use classes).

Our study is helpful to understand the natural exchange characteristics of nitrogen under relatively low atmospheric concentrations and to investigate the nitrogen background load. The comparison of long-term flux measurements can also lead to a significant improvement of deposition models.

Evaluating the effect of the urban forest on the flux of reactive gases and aerosols in the atmosphere using WRF-CMAQ model

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Urban forest is in the spotlight as a mean of reducing air pollutant in the cities, however it is still divided over the effect of forest on the air quality in urban areas. Plant ecosystem exchange nitrogen oxide (NOx), ozone, and volatile organic compounds (VOCs) with atmosphere through photochemistry reactions. Biogenic Volatile Organic Compounds (BVOC) which generated from the plant is two to three times more responsive than VOCs caused by human activities, and may change the concentration of reactive gases and aerosols flux in the air. In addition, the deposition of the particular matter on the surface of the plant and absorption of gaseous matter via stomata can act as a sink of these compounds. Based on these interactions between terrestrial ecosystem and atmosphere, there is a need to analyze quantitatively the fluxes of reactive gases and aerosols within the urban forest. We simulated the impact of urban forest on the flux of NOx, ozone, and VOCs using WRF-CMAQ model. First, according to the size of the forest and meteorological conditions, we analyze the spatial range of impact. Second, we investigated which extent BVOCs have an effect on the flux of NOx, ozone, and VOCs on the scale of urban forest. It suggested the way to consider the biosphere-atmosphere exchange of reactive gases and aerosols to assess the role of forest in urban area for air quality improvement.

Session 13: Education tools and methods

Oral presentations in session 13

ICOS Data at Your Fingertips

Claudio D'Onofrio (Department of Physical Geography, Lund University, Lund, SWEDEN), Team Carbon Portal (Department of Physical Geography, Lund University, Lund, SWEDEN)

ICOS aims to collect greenhouse gas measurements and observations in a consistent and documented way throughout Europe. The result is reflected in high quality datasets of concentrations and fluxes accompanied with the necessary ancillary data for different Ecosystems, Sea to Atmosphere exchange and Atmospheric concentrations. These data sets are available to the public at the ICOS Carbon Portal for download. The ICOS data life cycle guarantees access to the data with a persistent identification (PID) for reproducibility and citation to provide provenance and consistency. However, advances in computing, the ubiquitous internet availability and the size of data create a paradigm shift towards Virtual Research Environments, where computing is moved closer to the data. ICOS provides two pathways to access the data. One is the conventional data download approach and the second is to access data directly on our server or in-memory on your own computer. We will present a short overview of the data life cycle management and the pros and cons of both approaches to the data.

A python library has been developed to ease the access to the data. As a rule of thumb: everything you can 'preview' in the ICOS data portal, is accessible. The examples we provide are based on ICOS Level 2 data products. To access the data, the only information needed is the PID of the digital data object. The digital object identifier can be obtained through the online data portal or by running a SPARQL query. Calling the library with the PID returns a pandas data frame with the data; including information about the units, station (latitude, longitude), timestamps, sampling height etc. We have simplified the current complexity of access to a single line of code.

We provide built-in "lists" of PID's (results from SPARQL queries), for example, 'all level 2 data of atmospheric CO2 concentrations' to provide simple tools to compare different stations and regions in Europe. An advanced user can easily extend the suggested queries or add new ones.

The ICOS Carbon Portal runs a public Jupyter Hub, with (Python)-Notebooks to provide a reliable, fast and consistent way to access the data. The library can be installed on any personal computer as well, as long as there is a Python installation available. The intention of this library is to make ICOS data easily accessible for research, outreach programs and education.

Learning multidisciplinary climate change competencies

Laura Riuttanen (Institute for Atmospheric and Earth System Researc, University of Helsinki, Helsinki, FINLAND), Taina Ruuskanen (INAR, University of Helsinki, Helsinki, FINLAND), Mikko Äijälä (INAR, University of Helsinki, Helsinki, FINLAND), Lauri Katja Anniina (INAR, University of Helsinki, Helsinki, FINLAND)

What are the competencies we need in order to tackle the challenges of the current climate change? The urgent societal need for climate action requires us to rethink climate education in all levels of education. Due to the interconnectedness of the challenges, new collaborations between different fields of science as well as society are needed (Lehtonen et al., 2018). What is the role of atmospheric and Earth system sciences education and what kind of collaboration do we need?

A very recent study by Riuttanen et al. (in prep) studied what competencies do atmospheric and Earth system scientists teach in seven European countries, and how they foresee the importance of different competencies for the students to learn. We also asked about teacher experiences and wishes related to teaching collaboration. Results show the need to identify and redefine more specifically climate change related competencies.

University of Helsinki has long traditions in multidisciplinary teaching, as INAR has organized research-oriented intensive courses for 20 years. In these courses students focus on real research questions, work in small groups with access to comprehensive long-term datasets, and the horizontal learning principle enables everyone – students, supervisors, and lecturers – to adopt both the role of learner and teacher (Lauri et al., 2019). We found out that the use of real data and authentic scientific questions increases the motivation of both students and teachers (Ruuskanen et al., 2018).

In Finland, Climate University was established in 2018 to advance multidisciplinary collaboration in climate change and sustainability teaching in higher education (blogs.helsinki.fi/climateuniversity). Climate University is a national collaboration of 11 universities, coordinated by the University of Helsinki Institute for Atmospheric and Earth System Research INAR. Six open online courses will be produced in multidisciplinary collaboration by the end of year 2020: (1) Sustainable.now – sustainability on the time of climate change; (2) SystemsChange.now – systems thinking tools for the sustainability transition; (3) Solutions.now – project course on climate solutions in work life collaboration; (4) Climate.now for high schools; (5) Statistical tools for climate and atmospheric data, and (6) ClimateComms.now – course about climate communication.

The importance of training for long-term operation of atmospheric greenhouse gas observations

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The atmospheric abundance of greenhouse gases is one of the Essential Climate Variables defined by the Global Climate Observing System (GCOS). To be most useful, atmospheric observations need to be of known quality, of high precision and global consistency. Coordinating networks such as the Integrated Carbon Observation System (ICOS) in Europe facilitate highly compatible data over a large area. However, the availability of long-term, consistent, and publicly accessible greenhouse gases observations of adequate quality is still sparse in other regions of the world, like in the tropics and developing countries. There, monitoring efforts often depend on individual efforts and bilateral partnerships while regional collaboration networks are usually lacking.

This presentation reports on the experience made within the GAW Quality Assurance/Scientific Activity Centre (QA/SAC Switzerland), which is closely linked to the World Calibration Centre also hosted by Empa (WCC-Empa). QA/SAC Switzerland supports GAW stations in data sparse regions to start, resume and maintain such observations sustainably. It focusses on training, twinning, and capacity building, i.e. provides technical support of GAW stations, advice for adequate instrument selection, instrument operation and calibration strategies, and it assists in data quality and data submission issues. We highlight experiences and lessons-learnt from support and teaching activities at the GAW Training and Education Centre (GAWTEC), other training sessions, one-to-one trainings, and during maintenance visits and station audits. Our experience shows that – when starting with basic infrastructure and willingness to perform high-precision trace gas observations in a remote environment – it typically takes a decade to reach the status of a fully autonomous monitoring station with high-quality data, and good visibility within global scientific community. Our presentation critically assesses the available documentation, identifies shortcomings, and suggests the preparation of straightforward checklists, guidelines and video-tutorials dedicated to unexperienced users and novices.

ICOS atmosphere station characterization tool

Ida Storm (Dept of Physical Geography and Ecosystem Science, Lund University, Lund, SWEDEN), Harry Lankreijer (Lund University, Lund, SWEDEN), Karolina Pantazatou (Lund University, Lund, SWEDEN), Claudio D'Onofrio (Lund University, Lund, SWEDEN), Ute Karstens (Lund University, Lund, SWEDEN), ICOS CP team (Lund University, Lund, SWEDEN)

The aim of the ICOS atmosphere station characterization tool is to provide users of ICOS data with basic information on what potentially influences the tracer concentrations at the station and to support them in the selection of stations. The station characterization tool is based on the stations' influence regions, also called footprints. Footprints are calculated by atmospheric transport models – the STILT (Stochastic Time Inverted Lagrangian Transport model) model in this case – and indicate the contribution of the surface exchange fluxes to the atmospheric concentration of the tracer.

As these footprints can be computed on demand in the ICOS footprint tool, and all parameters derived for the station characterization, as well as the visualizations used to display them, are generated in a Jupyter Notebook, the characterization can be produced also for hypothetical stations, e.g. to aid in the process of picking a station location.

The idea is that these footprints can be used to characterize the average sensitivity of a station to different influences, i.a.:

•anthropogenic CO_2 emissions based on the EDGAR (Emission Database for Global Atmospheric Research) emission inventory,

•biospheric CO_2 uptake and respiration based on the VPRM (Vegetation Photosynthesis and Respiration Model) model,

•land cover (e.g. forest, crop land, pastures, urban, ocean) based on the CORINE (Coordination of Information on the Environment) classification,

•population density based on GEOSTAT,

•emissions from point sources based on the E-PRTR (The European Pollutant Release and Transfer Register) database

•Radiocarbon emissions from nuclear power plants and fuel reprocessing stations reported in The RADD (RAdioactive Discharges Database) database.

The station's total average sensitivity and sensitivity within certain distances of the station are further investigated by aggregating the footprints on different time scales (e.g. seasons, months or specific dates).

Many different visualization techniques to present the resulting parameters have been explored including bar- and line graphs, pie charts, maps and windroses. The poster will display the station characterization results of selected stations, but whereas these stations will be in focus we recognize the importance of maintaining the possibility to see the results in relation to the other stations. For this, we explore the use of a parallel coordinates graph.

Poster presentations in session 13

Adaptation and mitigation Climate change and environmental degradation processes affecting all types of Agricultural activities

Dr. Kakha NADIRADZE (Sustanable Agriculture Association for Farmers Rights Defense, AFRD, Tbilisi, GEORGIA)

Farmers, Ag Cooperatives, Smallholders must be ready for adaptation and mitigation Climate change and environmental degradation processes affecting all types of Agricultural activities, including Aquafarming, Crop Farming, Beekeeping in all countries. Very important the development of National Policies and Strategies (with efficient Action Plans) on minimization of negative impact of Climate Change processes are serious about contributing to the reduction of poverty in the rural and urban communities in which they work, they must give consideration to the climatic and environmental hazards, which impact in Agriculture, Soils Degradation and weather constraints. Climate change and environmental degradation are proceeding rapidly and are already affecting many communities in developing countries like Georgia, where Farmers are facing the negative impact of Climate Change and environmental degradation caused by Greenhouse gases. It is increasingly acknowledged in the adaptation to climate change guideline's that factors to be minimized. Such National Policies must explore adaptation strategies by focusing on livelihood diversification in the face of the most recent problems that are indicated by Farmers during observation last decades and it is shown as a major barrier to adopt these impacts without knowledge and capacity building.

Remote sensing supported sea surface pCO2 estimation and variable analysis in the Baltic Sea

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Oceans, particularly marginal seas, represents a highly variable and to some extent still highly uncertain component of the global carbon cycle. The partial pressure of carbon dioxide (pCO_2) in sea-surface show large temporal and spatial variations driven by complex mechanisms. The Baltic Sea is a brackish sub-arctic inland sea with complex settings, we here use variables from remote sensing data and numerical models to derive monthly maps of sea surface partial pressure of CO_2 (pCO_2). The random forest algorithm is introduced to construct a regression model. In addition, we analyze what input variables that are of importance for the pCO_2 estimates. The resulting maps of pCO_2 for the Baltic Sea from 2002 to 2011 have RMSE of 48 µatm and R^2 at 0.68. The pCO_2 maps derived presents realistic seasonal variation and spatial features of sea surface pCO_2 in the Baltic Sea. The variables of importance for constructing of the maps varies between seasons, which indicates that the processes controlling pCO_2 alters. Photosynthetically available radiation (PAR) is the most remarkable variable when the pCO_2 estimate is conducted in the entire Baltic Sea reflecting the seasonal cycle, in addition is SST of great importance. For limited areas other parameters add to the result, aCDOM is equivalently important to PAR when the pCO_2 is estimated in Gulf of Finland. The relevance of the variables, however, showed significant differences between sub-basins. This demonstrates that the controlling mechanisms of pCO_2 concentration differ between the sub-basins and seasons.

Session 14: Vulnerability of the Carbon Cycle, part 2

Oral presentations in session 14

Extreme productivity patterns during the spring bloom 2018 in the central Baltic Sea suggest vertical nutrient shuttling: Unforeseen surprises for the fight against eutrophication in a warming world?

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The Baltic Sea is one of the largest brackish water systems on Earth and encounters high anthropogenic pressures due to the 85 Million people from 9 nations living in its huge drainage basin. Strong international management actions aim to alleviate the anthropogenic pressures and to foster the development towards a sustainable ecosystem. However, Northern Europe is projected to encounter stronger climate-driven changes than on global average, and increasing awareness arises that these changes might counteract the pan-Baltic effort for ecosystem restoration of the Baltic Sea.

The 2018 European heatwave led to the highest sea surface temperatures in some areas of the Baltic Sea ever recorded in summer. In-depth analysis, however, reveals that the most extreme deviation from long-term monthly solar irradiation over the Baltic Sea actually occurred in May, and strongly affected biological production during the spring bloom, the major productive period in the central Baltic Sea.

By compiling data from the ship of opportunity (SOOP) Finnmaid, an ICOS ocean platform, Finnish BGC-Argo floats, HELCOM monitoring data, and remote sensing, the following mechanistic picture evolves: (1) by mid-April, rapid surface warming had led to the development of a shallow thermocline, complete depletion of inorganic nutrients in the upper 15 m, but still considerable loads of nitrate and phosphate below the mixed layer; (2) until mid-May, nitrate depletion down to 60m depth evolved, despite the persistent thermal stratification at the surface; (3) carbon system observations and vertical Chl a data show that the productivity was focused in the mixed layer, where pCO_2 dropped down to 40 µatm, indicating unpreceded high carbon fixation in the upper layer, but decoupled from the deeper-reaching loss of nitrate and phosphate; (4) in combination to the unpreceded high occurrence of of the dinoflagellate Peridiniella catenate, this suggests that the bloom was sustained by vertical shuttling of nitrate towards the mixed layer.

Based on integrated analysis of the data obtained on SOOP Finnmaid and by remote sensing, we assess the spatial extend of the unusual high spring surface productivity to be confined to the northern parts of the Baltic Proper, whereas the mid-summer cyanobacteria bloom covered almost the entire central Baltic Sea, reaching an areal extent of about 200.000 km2 during that year.

If the 2018 meteorological situation was to appear more frequent in the course of regional climate change, this “glimpse into a possible future” points to potential biogeochemical feedbacks, with implications on indicators used to track and on measures to combat eutrophication, as pursued under the HELCOM umbrella. The work also shows the enormous potential to increase our knowledge of European marine ecosystems by a combined use of large-scale European Infrastructures, including

ICOS, ARGO, HELCOM monitoring activities and the Sentinel Programme of the Copernicus Earth Observation Programme.

Effect of the 2018 drought on methane and carbon dioxide exchange of northern mire ecosystems

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In 2018, North-Western Europe experienced very dry and warm summer. These conditions can have considerable effects on the functioning and greenhouse gas exchange of terrestrial ecosystems. Peat-forming wetlands, or mires, are a characteristic component of the North-European boreal landscape, and crucial for long-term carbon storage as well as for methane emission. We have analyzed the effect of the drought on greenhouse gas (GHG) exchange of five North European mire ecosystems in Sweden and Finland in 2018. The low precipitation and high summer temperatures in Fennoscandia led to a lowered water table in majority of the mires. This lowered both carbon dioxide (CO_2) uptake and methane (CH_4) emission during 2018, turning many of the mires from CO_2 sinks to sources during this year. The changes in methane emission and total GHG exchange, expressed as CO_2 equivalent, were significantly correlated with change in water table position. The calculated time-evolving radiative forcing due to the changes in GHG fluxes in 2018 showed that the drought-induced changes in GHG fluxes first resulted in a cooling effect lasting 15-50 years, due to the lowered CH_4 emission, which was followed by longer-term warming phase due to the lower CO_2 uptake in 2018.

Impact of the 2018 drought on the carbon balance of terrestrial ecosystems in Northern Sweden - integrating measurements and modelling

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The 2018 European drought was marked with record-breaking temperatures and water deficits in many parts of Europe. We investigated the response of the terrestrial carbon balance to the 2018 drought using modelled and observed concentration and fluxes of CO_2 over the Scandinavian domain. Net Ecosystem CO_2 Exchange (NEE) estimates from four different vegetation models (LPJ-GUESS, VPRM, SiBCASA and ORCHIDEE) were used in forward simulations with the LUMIA (Lund University Modular Inversion Algorithm) transport model to connect with carbon cycle observations (atmosphere and ecosystem) at different spatial scales for the period 2016-2018. At the regional scale, ecosystem carbon fluxes from the vegetation models and modelled concentrations from the LUMIA forward runs were compared with tall tower eddy covariance (EC) flux observations and in situ concentration measurements at the Svartberget (SVB) ICOS atmospheric station. The NEE flux components (GPP and Reco) were also analyzed at seven different geographical locations in Scandinavia. We find that the model-measurement agreement was in general good, though with some discrepancies. Our results indicate similar reductions in the net CO_2 uptake during drought for ecosystem models and flux observations. However, our study overall highlights the need to further improve vegetation models through model-data inter-comparisons at both large and small spatial scales using transport models and EC flux observations.

Spring enhancement and summer reduction in carbon uptake during the 2018 drought in northwestern Europe

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We used observed changes across the Integrated Carbon Observation System (ICOS) network, biosphere and inverse modeling, and remote sensing to analyse the gross primary productivity (GPP), total ecosystem respiration (TER), and the resulting net ecosystem exchange (NEE) of carbon dioxide by the terrestrial biosphere during this extreme event. We compared GPP simulated using the Simple Biosphere Model version 4 (SiB4) to independent, yet highly correlated, reductions in productivity from the remote sensing products sun-induced fluorescence and vegetative near-infrared reflectance, as well as eddy-covariance measurements taken at ICOS ecosystem sites.

All products were in good agreement over GPP, NEE, TER, and soil moisture as applicable and indicated a significant decrease (SiB4: -57 TgC) in the summer uptake of carbon dioxide from the atmosphere by the region's vegetation, covering an area of 1.6 million km². We found low soil moisture to be the primary stress factor causing this reduction in uptake. We used the predicted NEE of SiB4 as a biosphere prior for the CarbonTracker Europe (CTE) inverse model, and assimilated data from the densely-sampled ICOS

network of atmospheric sites. We found a similarly strong drop in NEE (52 to 83 TgC) during the July-September period, offset by increased uptake during the spring when conditions were warm and sunny but soil moisture was still widely available.

Impact of the 2018 drought on carbon, water and energy exchange of a mature Sitka spruce and a restock site on organo-mineral soil

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Forest play an important role in mitigating climate change. In the UK woodlands and forests cover 3.2Mha, 13% of the land of which 6.809 km2 are on organo-mineral soil (peaty gley and peaty podsol). Sitka spruce is the major fast-growing conifer species, predominantly managed as monoculture even-aged plantation with rotation lengths of less than 50 years using a "patch clear-felling" system. However, increases in global temperatures resulted in the recent hot and dry year of 2018. Such extreme event is expected to have a big impact on carbon, water and energy exchange of Sitka spruce, a species suitable to humid conditions. Furthermore, its business-as-usual management of patch clear-felling, may not be suitable under future drought events. In this study, we used flux data from Harwood Forest GHG monitoring site in Northumberland UK to 1) quantify the impact of 2018 drought on carbon, water and energy exchange of a mature Sitka spruce plantation and a recently restocked clear-fell site and 2) understand the underlying limitations of drought on ecosystem processes. We found that forest fluxes were mainly driven by water availability making trees susceptible to drought, however, after clear-felling fluxes were influenced by temperature making them vulnerable to heatwaves. Drought in 2018 also reduced net assimilation of the standing mature forest by 30% comparing to the mean of the previous three years. On the other hand, it inhibited the restock site recovery to a sink and turned it into a stronger source, increasing seedling mortality. Finally, drought increased losses of both energy and water and reduced the water use efficiency of mature trees.

Poster presentations in session 14

Proofs of non-stomatal limitations of potato photosynthesis during drought by using eddy covariance data

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Water stress in one of the main limiting factors in agro-systems, causing a reduction in gross primary production (GPP) and by extend, yields. However, it is still unclear to attribute whether the limitations of photosynthesis originate from a strict stomatal control (SOL) or from other non-stomatal limitations (NSOL). In this study, we investigated the effects of drought on potato crop by using eddy covariance data at the Lonzée Terrestrial Observatory during three consecutive cultivation periods (2010, 2014 and 2018). Regardless the years and the timing of the drought appearance, the maximum carboxylation rate Vcmax (one of the NSOL) was reduced with decreasing REW, while the stomatal sensitivity to GPP parameter in the Medlyn et al. model (G1-SOL) remained constant. We showed that below the REW threshold of 0.55 ± 0.05, the non-consideration of NSOL in the ecosystem CO2 model led to an overestimation of the modelled GPP, which was about three times higher than its unstressed corresponding value. As a result, decreasing Vcmax while maintaining G1 constant was sufficient to reproduce GPP and canopy conductance dynamics during drought. At a sub-daily scale, the intrinsic water-use efficiency did not vary during drought, neither its dependence on VPD nor its hourly dynamics. This reinforced the hypothesis of direct and feedback effects of NSOL on canopy conductance and photosynthesis, which was supported by the uniform coupling between carbon and water fluxes. We recommend the implementation of NSOL in ecosystem CO2 models since non-stomatal factors were responsible for the decrease in potato crop GPP during drought.

Resistance and resilience of semi-natural plant communities to extreme drought

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The stability of plant communities is predicted to be strongly influenced by the increase in the magnitude and frequency of climate extremes. However, the observed impacts of specific climate extremes are highly variable. For example, the responses of plant communities to an extreme drought range from surprisingly high stability to significant reductions of ecosystem functions and/or changes in species composition. This may be because most studies focused on the effects of a single drought intensity over short time periods which challenges the comparability among studies. Furthermore, the majority of drought impact studies stem from freshly sown, artificial plant communities while very little is known about the drought impact on established semi-natural plant communities.

In this study, we studied the impact of two drought intensities on semi-natural temperate grasslands over four generations. We show consistent drought effects with increasing intensity on community biomass and species composition. Specifically, biomass was significantly reduced with increasing drought intensity. Interestingly, this significant reduction was reversible with the removal of the drought, i.e. plant community productivity was not resistant but resilient to extreme drought. Our study challenges the applicability of results from artificial communities to semi-natural ecosystems.

Analysis of floodplain forest sensitivity to drought

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Floodplain forests are very complex, productive ecosystems, capable to store huge amounts of soil carbon. With increasing occurrence of extreme events, they are today among the most threatened ecosystems. Our study's main goal was to assess the productivity of a floodplain forest located at Lanžhot in the Czech Republic from two perspectives: carbon uptake (using an eddy covariance method) and stem radius variations (using dendrometers). We aimed to determine which conditions allow for high ecosystem production and what role drought plays in reducing such production potential. Additionally, we were interested to determine the relative soil water content threshold indicating the onset and duration of this event. We hypothesized that summer drought in 2018 had the most significant negative effects on the overall annual carbon and water budgets. In contrast to our original hypothesis, we found that an exceptionally warm spring in 2018 caused a positive gross primary production (GPP) and evapotranspiration (ET) anomaly that consequently led in 2018 to the highest seasonal total GPP and ET from all of the investigated years (2015-2018). The results showed ring-porous species to be the most drought-resistant. Relative soil water content threshold ~0.45 was determined as indicating the onset of drought stress.

The role of drought on element release and the velocity of litter decomposition

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With climate changing alarmingly quickly, and earth is heading towards a climate emergency, it is increasingly important to derive scenarios for the response of biogeochemical ecosystem processes to climate change. Unfortunately, the forecast of the carbon cycle remains highly uncertain because of the interplay of abiotic and biotic effects. For example, essential processes such as decomposition of plant litter are directly influenced by climate (e.g. acceleration with increased precipitation and temperature), but indirect climatic effects operating via plant or microbial species composition may either offset or enhance direct climate effects. Therefore, it is crucial, albeit difficult to disentangle the influence of single climatic variables such as precipitation from the indirect effect of climate on litter decomposition. To do so, we combined observations and reciprocal litter transplants along a steep precipitation gradient in Chile with in situ manipulation of precipitation with rainout shelters. We analyzed the response of both mass loss of the decomposing litter and element losses to natural and experimentally induced precipitation change, as well as to litter origin. When ignoring origin effects and species-specificity, there was an unequivocal positive effects of precipitation of decomposition rates. However, litter decomposition of local litter, in its own climate, did not differ much among climates, highlighting the overriding effect of indirect effects of climate via (species-specific) litter quality. Specifically, because litter quality was higher on the arid site of the gradient. Overall, we suggest that popular space-for-time approaches based on comparing decomposition of local litters along climate gradients may be misleading, and should be combined with mechanistic experiments. Here, our experimental results suggest a retarded decomposition of litter and thus less recycling of carbon and nutrients with the predicted precipitation decrease in Chile.

Session 15: Innovation and uncertainty in observation techniques, part 3

Oral presentations in session 15

Effect of summer drought on soil CO_2 efflux in four forest ecosystems

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Annual soil respiration of temperate forests has been mostly driven by temperature. The current alteration of precipitation due to climate change, especially more frequent long dry periods, can substantially affect inter-annual variability of forest soil respiration. Recently, Central Europe suffered from low precipitation during summers in 2015 and 2018 and the aim of this study is to determine monthly and seasonal amount of CO2 released from soil of four forest ecosystems in the Czech Republic during these dry and normal years. We measured continuously soil CO2 efflux, soil temperature, precipitation and soil moisture in a mountain young Norway spruce forest, an old Norway spruce forest of middle altitude, a beech forest, and a mixed broadleaf forest. We found a significant decrease in soil CO2 efflux during summer 2015 and 2018 in all forest ecosystem except for the mixed forest which, probably thanks to the closeness of the river, did not suffer from low soil moisture. In this ecosystem, the inter-seasonal variability of soil CO2 efflux was driven by soil temperature. In the other forest ecosystems, the summer drought decreased seasonal soil CO2 efflux and its inter-seasonal variability positively correlated with annual precipitation rather than soil temperature. Our results show that reduced precipitation in summer decreases the seasonal amount of CO2 released from soil in most of the forest ecosystems but that it also depends on the forest location connected with other conditions.

Measuring isotopic N_2O, CO_2 and CH_4 soil flux with Cavity Ring-Down Spectrometer for soil flux measurements

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Atmospheric concentrations of N_2O, CO_2 and CH_4 are currently steadily increasing, and soil processes are playing an important role in the nitrogen and carbon cycle. Stable isotope analysis of these trace gases is a valuable tool to better understand production and consumption pathways in soil and this process understanding will ultimately help to reduce greenhouse gas emissions from agricultural soils.

Here we present the integration of two cavity ring-down spectrometers (CRDS) for continuous stable isotope analysis of N_2O, CO_2 and CH_4 with 12 automated soil flux chambers. The measurements were performed at a long-term field experiment site located at Ultuna, Uppsala, Sweden. The site has been in agricultural use (predominantly C3 crops) for at least 300 years before the establishment of the experimental trial. Nitrous oxide concentrations, bulk $\delta^{15}N$ and $\delta^{18}O$ as well as the site-specific isotopic composition (δ15Nα, δ15Nβ) were measured with a Picarro G5131-i CRDS instrument. Carbon dioxide and methane concentrations and the stable carbon isotope composition ($\delta^{13}C$) were measured with a Picarro G2201-i dual carbon isotope analyzer. The analyzers were coupled in parallel and integrated with 12 Eosense eosAC automated soil flux chambers coupled to an Eosense eosMX multiplexer. The chamber measurements were performed in a recirculation configuration. Each chamber was located on one of four fertilizer treatments (Unfertilized, Calcium Nitrate, Ammonium Sulphate, Calcium Cyanamide).

We will present concentration, gas flux and isotope data from this field study and discuss the potential and technical considerations for continuous isotopic flux measurements in the field. We will also present a new soil flux chamber from Eosense, the eosAC-LT. This highly customizable chamber has a large footprint (0.21 m^2) that is ideal for monitoring N_2O emissions, internal mixing fan and two auxiliary sensor ports. Customization features include transparent or opaque chamber designs and custom chamber height with optional stacking bases, allowing for observation gas exchange with vegetation and measurements of other ecosystem processes.

Assessment of regional atmospheric transport model performance using ^{222}Radon observations

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Atmospheric inversions provide a way of estimating greenhouse gas (GHG) fluxes and emissions from measurements of atmospheric GHG concentrations, independent from national reporting or inventories. Transport models are a central part of theses inversions and quantitative knowledge of their uncertainties is a pre-requisite for the inversion performance, as any unaccounted uncertainty or systematic error in the inversion system directly translates to errors in the flux estimates. In this study, we explore the ability of the Stochastic Time Inverted Lagrangian Transport model STILT to correctly simulate the diurnal variation of boundary layer transport by comparing model results with observations of atmospheric ^{222}Radon activity concentration at European ICOS stations. ^{222}Radon, the short-lived (t1/2 = 3.8 days) gaseous progeny of ^{226}Radium, which is a trace constituent of all soils, can escape the soil grains and make its way from the unsaturated soil zone into the atmosphere. This leads to a rather homogeneous ^{222}Radon flux from continental soils into the atmosphere, while fluxes from ocean surfaces are almost negligible. At continental sites, the short-term variability of atmospheric ^{222}Radon is mainly determined by diurnal or synoptic-scale boundary layer mixing processes. If its continental exhalation rate is known, ^{222}Radon can even be applied as a quantitative tracer for evaluating regional scale transport model performance. Here we evaluate not only the distribution as well as seasonal and diurnal variability of the ^{222}Radon activity concentration at typical ICOS tower stations, but also compare vertical profiles of ^{222}Radon at the stations KIT Karlsruhe (DE: 30m, 100m, 200m) and Cabauw (NL: 20m, 200m), which provide particular insight into the diurnal behaviour of the boundary layer dynamics in the STILT transport model.

Two-level Eddy Covariance Measurements Improve Land-atmosphere Flux Exchange Estimates over a Heterogeneous Boreal Forest Landscape

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In its original theory, a homogenous flux footprint area is a key assumption for eddy covariance (EC) measurements. Still, the EC technique is also applied over complex and non-homogenous terrain. Given the variable footprint sizes between day- and nighttime atmospheric conditions, the flux source areas

and their relative contribution to the net exchange differ, potentially resulting in a bias at the diel scale. The changing footprint characteristics have also implications for the partitioning of the net CO_2 exchange into its separate component fluxes (e.g., gross primary production and ecosystem respiration). Here, we explore land-atmosphere exchanges of energy, water vapor, and CO_2 over a heterogeneous managed boreal forest landscape (~68 km²) from EC measurements conducted at 60 and 85 m heights at the ICOS Svartberget atmospheric tower in northern Sweden. This 2-level set-up provides the unique opportunity to combine flux measurements of the higher level (85 m) during daytime and the lower level (60 m) during nighttime obtaining data taken with a less variable footprint area during the diurnal course. This allowed us to compare the results from single-level and combined-level measurements with the overall goal to identify the impact of source area heterogeneity and footprint variability on EC flux estimates.

We find that the change of the averaged footprint area (within 80%-contour line of footprint climatology) between day- and nighttime was reduced by 88% due to the 2-level-combination compared to the averaged area change at the higher level (85 m). The cumulated sums for the study period (mid-August 2018 until mid-August 2019) of gross primary production, ecosystem respiration, and latent heat flux increased about 7-10% in magnitude for the combined data set compared to the higher level observations. The balances of net CO_2 uptake and sensible heat flux decreased about 3% and 40%, respectively. The effect of the data set combination on diurnal and cumulated fluxes differed between seasons in response to day length and gaps in the observations, as well as the source area dynamics. Thus, our study indicates, that a 2-level EC set-up over heterogeneous terrain improves estimates of the land-atmosphere flux exchanges and their component fluxes.

Towards operational quantification of GHG exchange in heterogeneous agricultural landscapes and experimental plots

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With the increasing need to mitigate rising atmospheric greenhouse gas (GHG) concentrations more attention is being directed at the quantification of the GHG exchange characteristics of heterogeneous landscape assemblages that vary in land cover and land use. Whilst emission-limiting or uptake-enhancing management actions are often being proposed for specific land use most remain to be experimentally tested and validated at the landscape scale. This is a challenge because the typical size of different landscape elements (fields, afforested areas and unmanaged land at hectare scale) or experimental fields where emission reduction measures are being tested, is at the lower limit of what micrometeorological techniques such as eddy covariance measurements can deal with. With large heterogeneity the use of chamber measurements is also limited. The investments to be made in equipment are a challenge for operational monitoring of GHG budgets.

To address this we assess the feasibility of several options to acquire appropriate data in a way that is achievable for stakeholders, such as land managers and regional authorities. We use existing and new flux data from an agricultural landscape in the North of the Netherlands to: 1) compare paired eddy covariance (EC) data and automatic chamber (AC) data to test the representativity of small footprints. Results from a test site on drained meadows show almost identical CO2 fluxes. Future research should compare grass length and soil moisture of EC- and AC footprints; 2) test simplified alternatives to EC, such as those relying on concentration variances. Data from the peat meadow site suggest that time-averaged fluxes can be estimated in an empirical way with reasonable accuracy from concentration variances; 3) analyse the value of information gathered with mobile, roving/temporary EC approaches interpolated with gap filling models. The indications are that the values and variability of fluxes is largely conserved and predictable within seasons.In all these analyses, we will consider the trade-offs between the need for accuracy and pragmatism in operational practice.

Poster presentations in session 15

From leaf to ecosystem: seasonal CO_2 exchange over a winter oilseed rape crop

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We quantified net ecosystem CO_2 exchange (NEE) in a winter oilseed rape (Brassica napus L.) crop using the eddy covariance (EC) technique over a six-month period in 2016. Micrometeorological variables, leaf photosynthesis, soil respiration and yield were also quantified to identify the main factors governing carbon exchange for this site. We obtained an NEE value of -530 g C m^{-2} indicating the crop to be a large sink for atmospheric CO_2, with a continuous net uptake of carbon (-NEE) extending for a period of 130 days. Cumulative NEE was greatest in April (-181 g C m^{-2}) and May (-154 g C m^{-2}) coinciding with an expansion in leaf area and increased pod growth, respectively. Gross primary production (GPP) increased with photosynthetically active radiation (PAR) > 1400 μmol m^{-2} s^{-1} whilst leaf photosynthesis saturated at PAR levels of ~1000 μmol m^{-2} s^{-1}, indicating that light-limited photosynthesis beneath the canopy apex contributed significantly to seasonal CO_2 uptake. Moreover, the highest mean GPP rates of 7.2 g C m^{-} d^{-1} occurred briefly at post-anthesis (30th May – 11th June 2016) as both pods and upper canopy leaves received high levels of incident radiation. Our analysis indicates that winter oilseed rape's canopy structure maximises radiation interception at each distinct phenological stage of crop growth thereby enhancing GPP and NEE. Management practices such as timing of nitrogen fertiliser input and pre-harvest crop desiccation could also modulate NEE by altering the duration and rate of CO_2 uptake by the crop.

A novel robotic chamber system allowing to accurately and precisely determining spatio-temporal CO_2 flux dynamics of heterogeneous croplands

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The precise and accurate assessment of CO_2 exchange is crucial to identify terrestrial carbon (C) sources and sinks and for evaluating their role within the global C budget. The substantial uncertainty in disentangling the management and soil impact on measured CO_2 fluxes are largely ignored especially in cropland. The reasons for this lies in the limitation of the widely used eddy covariance as well as manual and automatic chamber systems, which either account for short-term temporal variability or small-scale spatial heterogeneity, but never both. To address this issue, we developed a novel robotic chamber system allowing for dozens of spatial measurement repetitions, thus enabling CO_2 exchange measurements in a sufficient temporal and high small-scale spatial resolution. The system was tested from 08th July to 09th September 2019 at a heterogeneous field (100m x 16m), located within the hummocky ground moraine landscape of northeastern Germany (CarboZALF-D). The field is foreseen for a longer-term block trial manipulation experiment extending over three erosion induced soil types and was covered with spring barley.

Measured fluxes of ecosystem respiration (Reco) and net ecosystem exchange (NEE) showed distinct temporal patterns influenced by crop phenology, weather conditions and management practices. Similarly, we found clear small-scale spatial differences in cumulated ecosystem respiration (Reco), gross primary productivity (GPP) and net ecosystem exchange (NEE) fluxes affected by the three distinct soil types. Additionally, spatial patterns induced by former management practices and characterized by differences in soil pH and nutrition status (P and K) were also revealed between plots within each of the three soil types, which allowed compensating for prior to the foreseen block trial manipulation experiment. The results underline the great potential of the novel robotic chamber system, which not only detects short-term temporal CO_2 flux dynamics but also reflects the impact of small-scale spatial heterogeneity.

Gap-filling continuously-measured flux data: a highlight of time-series-based methods

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Soil respiration is an important ecosystem process that releases carbon dioxide into the atmosphere. While soil respiration can be measured continuously at high temporal resolutions, gaps in the dataset are inevitable, leading to uncertainties in carbon budget estimations. Therefore, robust methods used to fill the gaps are needed. The process-based non-linear least squares (NLS) regression is the most widely used gap-filling method, which utilizes the established relationship between the soil respiration and temperature. In addition to NLS, we also implemented three other methods based on: 1) artificial neural networks (ANN), driven by temperature and moisture measurements, 2) singular spectrum analysis (SSA), relying only on the time series itself, and 3) the expectation-maximization (EM) approach, referencing to parallel flux measurements in the spatial vicinity. Six soil respiration datasets (2017-2019) from two boreal forests were used for benchmarking. Artificial gaps were randomly introduced into the datasets and then filled using the four methods. The time-series-based methods, SSA and EM, showed higher accuracies than NLS and ANN in small gaps (<1 day). In larger gaps (15 days), the performance was similar among NLS, SSA and EM; however, ANN showed large errors in gaps that coincided with precipitation events. Compared to the observations, gap-filled data by SSA showed similar degree of variances and those filled by EM were associated with similar first-order autocorrelation coefficients. In contrast, data filled by both NLS and ANN exhibited lower variance and higher autocorrelation than the observations. For estimations of the annual soil respiration budget, NLS, SSA and EM produced satisfying results with budget errors < 6% while ANN exhibited larger errors up to 16.0%. Our study highlights the two time-series-based methods which showed great potential in gap-filling carbon flux data (including eddy covariance data and non-CO2 greenhouse gas data), especially when other environmental variables are unavailable. The R code to perform the gap-filling with the four methods in this study is incorporated into the R package “FluxGapsR” freely available at https://github.com/junbinzhao/FluxGapsR/.

Session 16: Carbon exchange of atmosphere and reservoirs with long-term storage potential, and its verification

Oral presentations in session 16

Annual ecosystem carbon budgets across an abrupt permafrost thaw gradient in Northern Norway

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Global scale warming leads to permafrost thaw and the release of large amount of carbon to the atmosphere as CO_2 and CH_4, potentially accelerating global warming (i.e. positive feedback to climate change). However, there are large uncertainties concerning permafrost thaw and related carbon emissions as changes in soil hydrology associated with permafrost thaw affect the mechanisms controlling carbon mineralization. Thawing permafrost can lead to surface water accumulation in some areas and seasonal and/or permanent soil drying in areas where permafrost thaw opens new channels of water to penetrate the groundwater system. The complexity of the hydrologic response to permafrost thaw increases the challenge in generating reliable estimates of the permafrost C-climate feedback. Furthermore, limited observational data exist to quantify the effects of permafrost thaw on net tundra carbon budgets, let alone to constrain the underlying processes governing C release under aerobic and anaerobic conditions.

In 2017 we established a field gradient study in northern Norway (69° N), where recent degradation of permafrost created thaw ponds in palsa-mire ecosystems. The site exhibits a natural gradient of permafrost thaw, which also corresponds to a local hydrological gradient. To gain process understanding of how changes in local hydrology affects CO_2 and CH_4 release from permafrost soils we set up six transects along permafrost degradation gradients contained the following landscape units; vegetated palsa, bare soil palsa, thaw slump, and permafrost thaw ponds. We also installed open top chambers along each of the gradients, except for thaw ponds, to study the effect of enhanced warming on the different permafrost degradation states. In 2019 we added an additional landscape unit to each transect, sedge and sphagnum moss colonized thaw ponds. We have used a range of manual and automated techniques to measure changes in soil and water microclimate, biogeochemistry, and soil CO_2 and CH_4 concentrations and efflux across the permafrost thaw gradient.

Our observations show that permafrost thaw and landscape subsidence – both permafrost slumping and pond formation – increase annual net carbon loss. Preliminary results show that thaw slumps and thaw ponds roughly doubled annual CO_2 release compared to palsa with intact permafrost. These increases relate to enhanced CO_2 emissions in thaw slumps and a large release of CH_4 – calculated as CO_2 equivalents – for thaw ponds.

More recently an Eddy flux tower was established at the site to measure CO_2 and CH_4 emission for the catchment area including our study site in 2019. We envision to combine our plot-scale measurements with the Eddy flux tower data to upscale to the catchment and possible further extrapolate this to larger areas using satellite data.

How is the Ocean Anthropogenic Reservoir Filled?

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About a quarter of the anthropogenic fossil fuel CO_2 emissions are absorbed by the ocean. The rate limiting step for this uptake is the transport of the anthropogenic carbon (Cant) from the surface ocean where it is absorbed, to the deep where it is stored on a long term basis. While it is generally known that regions where dense waters form and sink from the surface to the deep ocean are important for the vertical carbon transport, the exact magnitude of these fluxes in different regions are uncertain. Here we use a transport matrix to reconstruct the pathways for Cant into the deep ocean. The time-evolving surface boundary condition for the Cant was determined by using surface pCO_2 from the Norwegian Earth System model and climatological distributions. The transport matrix connects 2806 possible surface sources to 74064 ocean interior grid cells assuming steady state circulation. We show that around one third of the ocean's annual uptake is stored in the deep ocean long-term reservoir below 1000 m. Although the Southern Ocean absorbs a large fraction of the ocean Cant, most of this is stored in the main thermocline due to the shallow overturning circulation. The Labrador Sea and, to a lesser extent, the Nordic Seas are the main contributors of the Cant injection to waters below 1000 m.

Operational decision tools for climate change mitigation: a case study for agricultural systems

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Understanding, predicting and minimizing the impacts of the ever-worsening climate crisis is getting more and more pressing everywhere in human life. Facing this challenge, the terrestrial carbon cycle takes the front line of the battle for two reasons. First, the carbon storage capacity of the terrestrial biosphere (vegetation and soil) is one of the most promising ways of removing large quantities of carbon dioxide (CO2) from the atmosphere. This potential is not only equal or greater than some other negative emission technologies (NETs), but it is also one of the least costly NETs with fewest negative environmental impacts. Second, it forms one of the greatest sources of uncertainty in future climate projections. This uncertainty is approximately equal to all other sources of uncertainties in policy, economics and technology combined.

For both making more reliable climate projections and developing natural carbon removal options, monitoring and forecasting systems of the terrestrial carbon cycle must be lifted up to an entirely new level. We urgently need better quantified knowledge on the terrestrial carbon cycle 1) to identify the sources of these uncertainties and the data types and quantities that are most helpful in reducing them,

and 2) to translate this knowledge into credible and reliable methods to monitor, model and report carbon cycle so that we can develop and verify effective practices of removing excess CO2 from the atmosphere.

In this study, we use process-based mechanistic models to synthesize a variety of measurements with our understanding of agricultural systems towards this goal. However, deploying these computer simulators for carbon cycle predictions is not without computational and statistical challenges: the models need to be connected to data streams for running them forward as well as for improving their predictions through a suite of analytical tools. Automatizing these data-model integration workflows not only for one model (or one type of model), but also for multiple (types of) models is crucial for promptly meeting the dispersed and variable needs of individuals, industrial partners, policy makers and the broader society.

Here we demonstrate an operational ecological model-data integration workflow that can perform model-based carbon cycle analyses by ingesting measurement data, weather data, remote sensing data, and update predictions in near-real time. This workflow is developed within an informatics toolbox called Predictive Ecosystem Analyzer (PEcAn) and tested for an agricultural carbon-farming site to quantify the carbon sequestered due to regenerative agricultural practices, in terms of both additionality and longevity. We further generated and assimilated synthetic observations at different intervals and combinations to inform future observational design and carbon accounting options. Our organized methodology of agricultural carbon monitoring and forecasting provides improved carbon cycle predictions and means of practical decision-making about mitigation and adaptation.

CO_2 increase and ocean acidification in the Southern Indian Ocean over the last two decades

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The Southern Ocean is recognized as a major player in the sequestration of anthropogenic carbon. As pH is naturally low at high latitudes, the increase in oceanic CO_2 raises particular concerns in this region were surface waters could become rapidly under-saturated with respect to carbonate. We used repeated observations collected over the last two decades (1998-2018) by the French monitoring program OISO (Ocean Indien Service d'Observation), conducted on board the Marion Dufresne (IPEV/IFREMER), to investigate the evolution of CO_2 and ocean acidification in the Southern Indian Ocean (45°S-57°S). South of the polar front in the High Nutrients Low Chlorophyll (HNLC) region our results show an increase in the fugacity of CO_2 (fCO_2) in surface waters during summer, close to the increase in the atmosphere (on the order of +2 µatm yr^{-1}) associated with a decrease in pH in the range of the mean global ocean trend (on the order of -0.0020 yr^{-1}). However much larger changes are found in the phytoplankton blooms in the vicinity of Crozet and Kerguelen Islands for both fCO_2 (between +3.3 µatm yr^{-1} and +5.5 µatm yr^{-1}) and pH (ranging from -0.0036 yr^{-1} to -0.0066 yr^{-1}). In all regions, the trends observed during summer are mainly driven by an increase in total carbon that is consistent with the accumulation of anthropogenic carbon evaluated below the summer mixed layer. Complementary data (from Argo and BGCArgo floats, biologging and satellite) will be used to investigate the rapid trends observed near Kerguelen and Crozet Islands.

Long-term intercomparison of two pCO_2 instruments based on ship-of-opportunity measurements in the Skagerrak

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The partial pressure of carbon dioxide (pCO_2) in surface seawater is an important biogeochemical variable because, in conjunction with the atmospheric concentration, determines the direction of the air-sea carbon dioxide exchange. Large-scale observations of pCO_2 are facilitated through the use of ships of opportunity (SOO) equipped with air-seawater equilibrators on their underway systems. The need for expanding the observation capacity and the challenges involving the sustainability and maintenance of traditional equilibrator systems led the community towards developing more simple and autonomous systems. Here we performed a comparison between the results of a membrane-based sensor and a shower-head equilibration sensor installed on two SOO between 2013 and 2018. We identified time and space adequate crossovers in the Skagerrak Strait, where the two ship routes often crossed. We found a mean difference of 10.7 ± 9.0 µatm and a correlation coefficient of 0.84 between the pCO_2 values recorded by the two instruments, which is a good agreement considering the dynamic nature of the environment and the difficulty of measuring from two different vessels. The membrane-based sensor was integrated with a FerryBox system on a ship with a high sampling frequency in the study area. We showed the strength of having a sensor based network with a high spatial coverage that can be validated against the traditional methods and this way we can achieve more accurate flux estimates. We conclude that the accuracy of membrane-based sensors is good enough for studies in dynamic coastal and continental shelf seas.

Poster presentations in session 16

The net ecosystem carbon balance of a nutrient-poor drained peatland forest in boreal Sweden

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During the past century, 1.5-2 million hectares of natural mires in Sweden have been drained for forestry purposes. Recent studies suggest that these drainage activities has significantly altered the carbon (C) and greenhouse gas (GHG) balances of these areas. However, the change in GHG exchange in response to historic drainage differs most significantly both in sign and magnitude depending on peatland nutrient status and climate conditions. Thus, accurate accounting of national GHG budgets calls for representative and robust empirical data for entire Sweden. To fill this knowledge gap, we evaluate the drainage impacts of a historically (i.e. ~100 years ago) drained nutrient-poor peatland forest in boreal Sweden. The specific aim was to estimate the net ecosystem carbon balance (NECB) and its component fluxes by collecting CO2 and CH4 flux data with eddy covariance (since March 2020) as well as with manual closed chambers (since 2018) over natural and experimental vegetation removal/trenched plots to estimate the various soil and plant associated component fluxes. Tree inventories, tree coring and litterfall production are conducted to estimate the net primary production of the tree layer. Weirs have been established to quantify the aquatic discharge C export . Together, these data will help to understand the NECB and its individual terrestrial and aquatic component fluxes. We then examine how well soil and environmental variables explain the temporal and spatial variations

in the individual C fluxes. We will further compare our measurements from this drained peatland forest with similar data collected at an adjacent natural mire EC site (established in 2019) and at the nearby (3km away) ICOS Degerö mire station where NECB components have been measured since 2004. Our initial data indicate that peatland drainage has altered soil and environmental conditions for vegetation growth and microbial activities, with significant effects on the CO2 and CH4 flux rates.

Greenhouse Gas Emissions from two Reservoirs in East Germany: Mechanisms and Quantification

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The emissions of carbon dioxide (CO_2) and methane (CH_4) from inland waters are an important but a currently inadequately considered component of the global carbon cycle. The emission rates are temporally and spatially highly variable, and the characteristics of gas release differ between CO_2 and CH_4. Reservoirs are special hot spots of greenhouse gas (GHG) emissions as damming and the resulting reduced flow velocity extent the residence time of water and increase sedimentation rates of decomposable organic material. Currently, there is little known about the actual emissions and temporal dynamic of CO_2 and CH_4 exchange from inland waters. Therefore, relevant processes, controlling the GHG emissions, are still only partly understood.

GHG emissions from reservoirs are determined by numerous hydro-chemical, biological and meteorological parameters. Therefore, emissions are variable in space and time as well as for different water bodies.

Until now there are no continuous long-term observations of GHG emissions at Central European reservoirs. Hence, there is a significant deficit of observations and data being representative for Central European conditions.

In the project TREGATA, we started a challenging hydro-chemical and micro-meteorological monitoring program to investigate GHG emissions from two reservoirs representative for Central Europe. A special topic is to investigate and to comprehend, how atmospheric and hydrological parameter affect and control GHG emissions. In detail, we study the influence of meteorological variables, trophic state and altering of water levels on CO_2 and CH_4 emissions. We successfully installed a complex micro-meteorological and hydro-chemical observation system on a floating platform to measure GHG emissions as well as to monitor energy balance and exchange, meteorological and hydro-chemical variables.

The observed temporal patterns of H and LE differ significantly to what is known for land surfaces. The maximum of H occurred in the early morning hours. In case of LE, the high positive nighttime fluxes are conspicuous. Nevertheless, the observed daily estimates of ET were only about half of what would be expected for land surfaces under similar atmospheric conditions. We also show budgets of CO_2 and CH_4 of two German reservoirs (Rappbode and Bautzen) during two measurement campaigns in 2017 and 2018.

Dynamics of carbon fluxes at different temporal scales for a youg spruce plantation

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We report on EC and auxiliary measurements performed in a young Norway spruce stand (planted in 2012) at Hoxmark, Southeast Norway. A detailed nonlinear time series analysis of the 20 Hz raw data reveals lag times and connection strengths between the variables which are dependent on the chosen temporal resolution. Meteorological, radiation and soil climate data were obtained at 10 min resolution and serve as covariates to explain Net Ecosystem Exchange patterns.

We present a new approach to decompose the raw data into signal and noise part, and conclude on the optimal temporal resolution separately for each variable (gas concentrations, wind, temperature).

Careful processing with a detailed footprint analysis, EddyPro calculations with time-dependent stand parameters and ReddyPro corrections reveals that the plantation is already a weak sink for carbon, despite its young age. The sink strength varies throughout the year, we present fingerprints for all major carbon fluxes.

Ecosystem CO_2 fluxes in an undisturbed mature spruce forest and adjacent clear-cut in southern taiga of European Russia

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Clear-cut harvesting impacts CO_2 exchange between the forest ecosystem and the atmosphere. Observational estimates of post-harvest ecosystem carbon dioxide fluxes are very limited for numerous geographical regions and forest types, including hemiboreal forests of European Russia. The ecosystem-atmosphere CO_2 exchange was analyzed using paired eddy covariance flux measurements in an undisturbed mature spruce forest (Ru-Fyo2 FLUXNET station) and an adjacent recently clear-cut site (CC) in the hemiboreal zone (southern taiga) of European Russia during 3 growing seasons following harvest. The CC site was a CO_2 source in the selected years. Cumulative net ecosystem exchange (NEE) for the period (6th of May – 18th of October) was 1553.3 $gC\cdot m^{-2}$ in 2016, 196.5 $gC\cdot m^{-2}$ in 2017, and 453.1 $gC\cdot m^{-2}$ in 2018. The Ru-Fyo2 site was a CO_2 source in the period in 2016 (NEE=21.5 $gC\cdot m^{-2}$)and sink in 2017 (NEE=-16.8 $gC\cdot m^{-2}$) and 2018 (NEE=-180.6 $gC\cdot m^{-2}$). Decreased gross primary production (GPP) explained the difference of NEE between the sites in the first two years after the harvest, while the difference of NEE in the third year was mainly connected with the increased TER rates at the CC site. Increasing Q_{10} coefficient for TER, light –use efficiency and water use efficiency (WUE) coefficients for GPP between the growing seasons at the CC site was detected. The obtained information is applicable for prediction of the consequences of harvesting for carbon balance of hemiboreal forests in European Russia.

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Session 17: RINGO

Oral presentations in session 17

TBA

Poster presentations in session 17

TBA

Session 18: Budgets, trends, and controls of GHG and other atmospheric constituents, part 3

Oral presentations in session 18

Spatial and temporal distribution of European CH_4 emissions from process-based models and CTE-CH_4 atmospheric inverse model

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Distribution of European CH_4 emissions are complicated, as various sources and sink processes affect the spatial and temporal changes. Spatial emission hot spots can be found from anthropogenic sources, and those from natural sources, mainly from wetlands, peatlands and mineral soils have high regional variations. Due to differences in the soil types and their responses to meteorological conditions, seasonal cycles of the natural CH_4 emissions in central and southern Europe, and northern Europe, are assumed to be different. Properly modelling both spatial and temporal distributions on regional scales are therefore challenging.

In this study, we examine European CH_4 fluxes using an atmospheric inverse model, CarbonTracker Europe-CH_4 (CTE-CH_4), where the fluxes are constrained by ICOS and global atmospheric CH_4 observations. The sensitivity of the estimated emissions are tested by using different prior flux fields. For anthropogenic sources, inventories from JRC EDGAR v5 and those prepared by Netherlands Organisation for Applied Scientific Research (TNO) are used. For the biospheric sources, estimates from two process-based ecosystem models (LPX-Bern DYPTOP and JSBACH-HIMMELI) and those from GCP-CH_4, which is provided as prior to GCP-CH_4 inversions, are used. LPX-Bern DYPTOP is a global model, JSBACH-HIMMLELI estimates European CH_4 fluxes at high 0.1 x 0.1 deg. resolution, and GCP-CH_4 is a climatological field, averaged from various process-based models. From the first analysis, we suspect the spatial distribution of the GCP-CH_4 may not be appropriate for describing the northern European CH_4 emissions. We examine the ability of the inverse model to correct those distributions and methods to improve the robustness of the inversion estimates. The results from the models will be evaluated using the ICOS atmospheric CH_4 and CH_4 flux observations.

Environmental drivers of GPP derived from CO_2, COS and SIF measurements

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Traditionally photosynthesis, or gross primary productivity (GPP), is defined from ecosystem scale carbon dioxide (CO_2) flux partitioning. While being a well-established method, it comes with deficiencies. Respiration is usually defined from temperature-dependent regressions that are based on nighttime flux measurements. This brings some problems from the assumption that respiratory processes would be the same under solar radiation and without radiation. Also, ecosystem scale flux measurements are not without problems during nighttime.

Carbonyl sulfide (COS) has been suggested to be a useful proxy for GPP as it shares the same pathway with CO_2 in the leaf stomata but, in contrast to CO_2, is not respired back to the atmosphere. Direct COS flux measurements bring a good GPP estimate when taking into account radiation dependency in leaf relative uptake (LRU) ratio that defines the leaf-scale normalized ratio of COS to CO_2 assimilation rates.

Recently solar-induced fluorescence (SIF) satellite retrievals have gained popularity in estimating photosynthesis especially due to their large spatial coverage. SIF gives a measure of photosynthesis dynamics at the light reaction level. Problems with remote sensing SIF are mostly related to measurement deficiencies especially in the boreal region, where cloudiness together with large solar zenith angles are limiting the number and precision of SIF observations.

In this study, we examine what are the most important environmental drivers in long and short time scales for GPP derived from CO_2, COS and SIF measurements in a boreal forest. Ecosystem scale CO_2 (2013-2019) and COS (2013-2017) flux measurements from Hyytiälä forest in Southern Finland are used together with SIF retrievals from the Nasa Orbiting Carbon Observatory (OCO-2) satellite (2014-2019). As all methods describe GPP from a different photosynthesis dynamics perspective, analysing the environmental responses gives new insights to carbon uptake processes under varying environmental conditions from daily to yearly scales.

Research infrastructures as modular platforms for reactive nitrogen deposition monitoring

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The need for large-scale monitoring of greenhouse gas (GHG) budgets has led to the emergence of highly standardised, globally distributed research networks that measure the biosphere-atmosphere exchange of CO_2, N_2O, and CH_4 with micrometeorological methods. These research infrastructures, like ICOS in Europe, or NEON in the US, are now fully operational. They routinely apply the eddy-covariance (EC) technique to measure the surface-atmosphere exchange of CO_2 and energy, and we argue that they are readily equipped with the necessary instrumentation to be used as extensible platforms for monitoring fluxes of additional atmospheric constituents.

Large-scale, representative, and nation-wide reactive nitrogen (Nr) deposition monitoring is desperately needed to evaluate the impacts of environmental protection efforts, and to identify ecosystems threatened by critical load exceedances. This need, however, is not met across a wide range of different ecosystems due to significant challenges involved with measuring Nr deposition. Operational research infrastructures may be extended with fast response Nr samplers to the existing EC setups, or with a combination of low-cost samplers and inferential modelling for individual compounds, as outlined below.

State-of-the-art implementations of Nr biosphere-atmosphere exchange models, especially for the case of NH_3, are nowadays able to reproduce measured fluxes to a reasonable degree of accuracy. Recent publications have aimed at applying these models on the plot-scale as a means of interpreting and gap-filling directly measured fluxes, and remedies for statistical issues with the application of inferential models with low-cost, low-resolution concentration input data are being developed. Routine measurements can directly be used within the models, such as stomatal conductance derived from measured CO_2 fluxes, thereby linking it to an important pathway of NH_3 plant-atmosphere exchange. These developments paint a promising picture for applying site-specific, data-driven parameterisations of Nr dry deposition inferential models at existing GHG monitoring flux towers with little additional cost and effort, thus creating a first step towards a global Nr deposition monitoring network in the short-term.

Considerable efforts have been made at demonstrating new technologies for long-term observation of total atmospheric Nr deposition with micrometeorological techniques. The Total Reactive Atmospheric Nitrogen Converter (TRANC) coupled to a fast-response chemiluminescence detector (CLD) can nowadays accurately and continuously measure Nr biosphere-atmosphere exchange within an EC system. As a long-term perspective, selected sites from existing infrastructures may be retrofitted with TRANC-CLD systems to generate continuous time-series of Nr deposition for a wide array of ecosystem. An upgraded TRANC-CLD system that separately measures reduced and oxidised Nr species and thus allows to differentiate between agricultural and industrial fluxes is currently being tested.

In this contribution, we explore short- and long-term perspectives on how ICOS can meet the need for large-scale Nr deposition network, thereby extending its capabilities far beyond greenhouse gas monitoring, and contributing to the understanding of global environmental change as a whole.

Recent trends in sources and sinks of methane

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Understanding the drivers of past climate change are crucial for understanding future warming. The recent temporal development in the atmospheric concentration of methane, the second largest greenhouse gas forcer, is not fully understood. The concentration leveled off at the beginning of the millennium with a renewed growth since 2007. In this study, we investigate two of the suspected causes: changes in OH-concentration and hence changes in methane lifetime, as well as changes in natural emissions from wetlands. The main sink of methane in the atmosphere is oxidation of OH. The trend in the OH sink is investigated using a chemical transport model (OsloCTM3). Changes in the anthropogenic emissions as well as meteorological factors contribute to an increased OH sink from 1990 to 2007, the end of the stabilization period. The second suspect for changes in methane concentration, changes in natural emissions from wetlands, are studied using the Community Land Model (CLM5.0).

Variability in annual tree growth – how much determination of the past is in the present response?

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Seasonal variation of radial stem growth of Norway spruce trees at the subalpine ICOS site CH-DAV were measured with automated point dendrometers since 1998. The 20 years lasting time series of stem radial size measurements of 10-15 trees include information about wood and bark growth and tree water relations with an hourly resolution. The mean annual increment of the - on average 240 years old - trees ranged between 10 and 15 mm and showed an ongoing trend towards an increasing annual growth.

We analysed the observed tree growth patterns in combination with environmental data (air and soil microclimate) as well as with biomass-related measures (e.g., crown transparency foliar nutrient contents) and applied different statistical and system analytical methods to quantify the explanatory weights of different factors. The models related current and past conditions to predict current stem growth.

We found a wide variety of factors indicating a significant explanatory weight of past conditions for the current year's growth response. As an example, correlation coefficient of crown transparency of the previous year with current growth was 0.31, whereas its current year values showed hardly any relationship. Most strikingly, partial least squares regressions indicated that previous year environmental conditions explained more of stem growth than the same conditions of the current year.

We discuss these legacy effects of past conditions on growth in the light of underlying mechanisms and show how much the lifetimes of organs (e.g. needles and sapwood) in respect to their turnover rates have the potential to explain the delayed responses. The work contributes to a better understanding of the partial decoupling of stem growth responses from current environmental conditions and aims to close the knowledge-gap between C source and C sink dynamics.

Poster presentations in session 18

Precipitation and temperature controls over wetland methane emissions estimated by atmospheric inversion modelling

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Changes in precipitation and temperature have profound effects on wetland ecosystem functioning. Prolonged periods of drought and low soil water table levels may turn peatlands into methane sink, while long term intense precipitation can turn not only peatlands but also the surrounding flooded upland mineral soils into significant sources of methane. Changes in temperature control the methane forming processes, high temperatures intensifying methane emissions at northern latitudes.

Here we study drivers of growing season wetland methane emissions from regional perspective, using optimised biospheric fluxes from Carbon Tracker Europe – CH4 atmospheric inversion model. The fluxes are solved in one degree resolution at northern wetland-rich regions, and in weekly time resolution. We will combine the fluxes with corresponding precipitation and temperature data, and study the regional variation in correlations assessing both permafrost and non-permafrost regions. We will also study impacts of exceptional long term drought, heat and flooding on methane emissions.

Towards an improved N2O budget inventory from 10 site-years measurement and analysis of key drivers

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At the global scale, agriculture represents 14% of total anthropogenic emissions of GHGs (Del Grosso et al., 2009), 46% of this amount being due to N_2O emissions from soils (UNEP, 2012). N_2O is a powerful and long-lived greenhouse gas (GHG) (IPCC, 2013) and its emissions from agricultural soils are related to physical-chemical parameters which depend on climate (temperature, rain…), soil properties (Robertson et al., 1989) and farming practices (irrigation, tillage, fertilizer type and quantity…) (Tellez-Rio et al., 2015). The IPCC Tier 1 emission factor remains widely used to estimate annual N_2O emissions from agricultural soils by taking into account the annual amount of N input only (fertilization and crop residue). However, not taking into account the environmental controlling factors may introduce high uncertainty in N_2O budget estimation. Our study aims at highlighting the key drivers of N_2O emissions from agricultural areas in the South West of France (temperate climate) and at proposing an improved, simple and accessible inventory methodology to estimate N_2O budget at crop plot and seasonal scale. For this purpose, we benefited from a unique long time series of daily N_2O fluxes (from 2011 to 2016) measured with 6 closed automated chambers on two ICOS sites with contrasted agricultural management (FR-Lam and FR-Aur).

N2O annual budget vary from 1.04 to 7.96 with an average of 2.7 ± 1.9 kgN ha^{-1} yr^{-1}. The effects of fertilization, waterfall (rain and irrigation), plant development, spring mineralization and deep tillage on N_2O emissions were investigated. Significant correlation between rain combined with deep tillage and spring mineralisation was found with R^2 of 0.97 and 0.98, respectively. We took advantage of these results to develop an empirical model, including mineral N input quantity, residual N, leaf area index and water input in order to estimate seasonal and annual N_2O budget. At the seasonal scale, the model output matched well with the observed budget, with a R^2 and a RMSE of 0.86 and 0.34 kgN ha-1 at FR-Lam and of 0.91 and 0.14 kgN ha-1 at FR-Aur, respectively. At the crop year scale the model also proved to be relevant as it gave good statistical scores with a R^2 of 0.98 and a low RMSE of 0.47 kgN ha-1 when binding data from both sites together. Using the IPCC Tiers 1 methodology gave lower and more scattered results with a R^2 of 0.46 and a more important RMSE of 1.50 kgN ha-1. For sites where N2O fluxes are not monitored despite their significance, and for inventory issues, that new methodology may be an alternative and a more precise inventory methodology than the IPCC Tiers 1 approach. It has also the advantage to require only few and accessible input variables.

Improving estimates of emissions of methane and carbon dioxide from strong emission region using analytical inversion system coupled with WRF-GHG tagged tracer simulations

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During May and June 2018, the intensive measurement campaign CoMet (Carbon dioxide and Methane mission) took place with a focus on greenhouse gases over Europe. The upper Silesian coal basin (USCB) in southern Poland was a specific target area of the campaign. CoMet aimed at characterising the distribution of CH_4 and CO_2 over significant regional sources with the use of a fleet of research aircraft, as well as validating remote sensing measurements from state-of-the-art instrumentation installed on-board against a set of independent in-situ observations.

In order to link atmospheric mixing ratios to source emission rates, high-resolution simulations with WRF-GHG v 3.9.1.1. (10 km x10 km Europe + nested 2 km x 2 km domain over the USCB), driven by short-term meteorological forecasts from the ECMWF IFS model and forecasts from CAMS (Copernicus Atmospheric Monitoring Service) for initial and lateral tracer boundary conditions were performed. Biogenic fluxes of CO2 were calculated online using the VPRM model driven by MODIS indices. Anthropogenic emissions over Europe were taken from the database of TNO, Department of Climate, Air and Sustainability (7 km x 7 km), augmented with an internal emissions database developed within CoMet that uses coal mine ventilation shaft emission measurements in combination with recent updates of the E-PRTR (European Pollutant Release and Transfer Register).

Tagged tracers were used to simulate a robust set of over 100 distinct anthropogenic sources of CH_4 and CO_2 from the study area, and these forward simulations were then used as the transport operator in an analytical Bayesian inversion system. Here we discuss the results of an analysis performed with the use of selected in-situ data measured over the course of the three-week campaign, including results and sensitivity tests of the inversion system.

Isotopic composition of methane from Swedish wetlands

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Globally averaged atmospheric mole fractions of methane and it's isotopic composition ($\delta^{13}C$) show different source contributions to the global budget than in years before 2007 (Nisbet et al., 2016). There is a trend toward ^{13}C-depletion in the global record and wetlands are probably one of the contributors to this depletion because they are all depleted in ^{13}C relative to atmospheric background. In many studies of global methane budgets, the $\delta^{13}C$ signature of wetlands are simplified to one value for all types of wetlands, instead of using unique ones for different regions. Studies conducted by Fisher et al., 2017 suggested that than more data from boreal regions (>60^0 N) should be delivered to improved regional and global models.

In our studies we took air samples from two areas: an ombrotrophic hemiboreal peatland in South-Western Sweden (Mycklemossen) and three peatlands under different stages of permafrost thawing in the sub-arctic area in northern Sweden (Kattejokk, Storflaket, Kursflaket,). Air samples from the hemiboreal peatland were taken from six chambers during two periods of the year, at the beginning and the ending of the growing season. Samples from the peatlands in the sub-arctic area were taken in the middle of the growing season, to be sure that the concentration gradient would be sufficient for obtaining high quality calculations of the isotopic signatures.

Air samples were measured by isotope ratio mass spectrometry (IRMS) systems at Utrecht University and at Royal Holloway, University of London. The results were analyzed using a Keeling plot approach.

We will present spatial variations of $\delta^{13}C$ signatures of methane emissions from Swedish wetlands. Average isotopic signatures for the measured wetlands were: Mycklemossen -79±2‰, Korsfalket -70±6‰, Storflaket -71±18‰, and Katejok -76±10‰. The hemiboreal peatland shows lower spatial variability compared to sub-arctic peatlands. Higher uncertainties reflect larger variability inside one wetland.

CH_4 emissions from oil and gas productions in Romania; an analysis of emission inventory reports and measurement-based data from ROMEO campaign

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Methane (CH_4) is a potent short-lived climate forcer, thus reduction of CH_4 emissions is an opportunity to combat global warming in a short period of time. About 25% of current global warming is due to CH_4 emissions and the oil and gas sector is one of the large sources of anthropogenic CH_4 emissions[1]. The EU aims to better understand the size and source of CH_4 emissions across the continent[2]. Officially reported emissions to UNFCCC suggest that Romania is one of the highest CH_4 emitters from oil and gas productions in Europe[3]. The ROMEO (ROmanian Methane Emissions from Oil and gas) campaign took place in October 2019 to independently and empirically quantify and attribute CH_4 emissions from oil and gas production infrastructures in Romania. ROMEO is part of Climate and Clean Air Coalition (CCAC) Oil and Gas Methane Science Studies – a set of international studies aiming at characterizing emissions from global oil and gas infrastructures. An international science team, centered around participants from the MEMO² consortium (https://h2020-memo2.eu/), performed measurements at different scales with two aircrafts, six cars, and two drones to quantify emissions at several scales. In total, emissions from about 200 individual wells and facilities were quantified, and more than 1200 were visited for "screening" in order to identify low and high emitting facilities for in-depth measurements as well as for deriving more representative emission distribution statistics. Mass balance calculations were used to quantify emissions from measurements on aircrafts and drones. These data will be used to improve the knowledge on emission patterns for emissions from oil and gas productions in Romania and point to potential mitigation actions. The inventoried CH_4 emissions from oil and gas productions in Romania show several large step-changes over time, which are likely not related to emissions changes but changes in the reporting methodology. In this presentation we summarize and compare the information from various inventories and relate these officially reported numbers to the results of the ROMEO project.

Characterisation of methane sources in Krakow, Poland, using high temporal resolution isotopic composition measurements

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Methane emissions are significantly contributing to the global atmosphere radiative forcing. A major concern is to reduce uncertainties associated with the source strength and partitioning of this important greenhouse gas. Isotope analysis is a widely used technique for source characterisation, but due to analytical challenges it has been difficult to obtain long-term high resolution time series that could help deciphering sources on hourly to daily timescales. At the same time, isotopic source signatures are not always well characterised and may vary in time and space, which is usually not taken into account in the analysis. Through long-term measurements of both ^{13}C and deuterium isotopic signatures in methane, we get a clearer knowledge of the actual methane sources influencing one region, as well as their temporal variations.

We report $\delta^{13}C$ and δD measurements that were performed in Krakow, at the AGH University, during 6 continuous months in 2018 and 2019. The wind was mostly coming from the west during this time period. Our hypothesis is that we can detect CH_4 emissions from the large coal mining area of Silesia, located in this direction. Our results are compared with time series obtained from an atmospheric dispersion model based on emission inventories and isotopic source signatures data from sampling campaigns in the region.

The average Keeling plot intercepts from the dataset are -47.8 ± 0.01 ‰ and -202 ± 0.05 ‰ for $\delta^{13}C$- and δD-CH_4, respectively. The isotopic source signatures generally correspond to emissions from fossil fuel sources: the relatively enriched δD-CH_4 confirms this hypothesis. From the analysis of individual events, we also detected emissions from nearby sources, especially the natural gas distribution network.

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A comparison of recent trends in methane emissions from China, the US, and Europe

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Methane is increasing in the global atmosphere, and there has been an ongoing scientific debate about the contribution of different emissions sources to these trends. We examine recent trends in emissions from three of the world's largest emitters of anthropogenic methane: China, the US, and the European Union, and we find that these trends are counter to what might be expected given recent government regulations and changes in methane-emitting industries. China is the world's largest emitter of anthropogenic methane, but these emissions should be changing: the country enacted a suite of regulations between 2006 and 2010 to curb emissions from coal mining, likely the country's largest methane source. We evaluate China's methane emissions using observations from the GOSAT satellite

and find the country's emissions rose by 1.1 +/- 0.4 Tg per year from 2010 to 2015, ~11–24% of the estimated global trend in methane emissions. This observed trend is consistent with pre-2010 trends and is largely attributable to coal mining, indicating that China's coal methane regulations have had no discernible impact on China's emissions. During the same time period, US natural gas production increased by ~50%, but a recent study using in situ methane observations did not find any large increase in total US methane emissions, in contrast to recent satellite-based studies. We evaluate three hypotheses to explain recent trends in satellite and in situ observations: (1) Methane emissions from O&G operations are increasing, but in situ atmospheric observations were not well-positioned to detect that increase; (2) Decreasing methane emissions from landfills and/or agriculture are offsetting growing emissions from the oil and gas industry; or (3) Leak rates from the oil and gas industry could have declined due to regulation and/or improved industry practices. We close by making recommendations for long-term monitoring of regional methane trends using atmospheric observations like those from the ICOS network.

Can multi-tracer analysis of tall tower concentration measurements be used for fingerprinting methane sources?

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The German Meteorological Service (DWD) runs eight ICOS Atmosphere tall tower stations across Germany since 2015. In addition to methane (CH_4) measurements, the continuously collected data include concentrations of carbon dioxide (CO_2), nitrous oxide (N_2O) and carbon monoxide (CO) at several heights on tall towers (up to 341 m at Gartow GAT station). At the station Hohenpeissenberg HPB, a Global Atmosphere Watch (GAW) station, reactive trace gas measurements are furthermore available for multi-tracer analysis.

The multi-tracer analysis presented here is based on the concept that methane will only be co-emitted for certain greenhouse gas emission sources and not others.

Utilising CO_2, CO and N_2O as indicators for fossil fuel combustion and biogenic/agricultural emissions, CH_4 sources and source strengths are identified. Where available, co-located or nearby in-situ NOx and O_3 measurements are included in the analysis.

Similarities and differences in vertical gradients of all species are used to aid fingerprinting methane sources in the towers' footprints. The potential and limitations of multi-tracer analysis of ambient concentration measurements from tall towers to constrain the methane budget is discussed.

Utilizing Remote Sensing of the Soil Freeze/Thaw State to Estimate Cold Season Methane Emissions in the Northern Hemisphere

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The northern biospheric methane emissions are characterized by a strong seasonal cycle: the emissions are high in summer when the soil is thaw and moist and low in winter when the soil is frozen. Still, the emissions are non-zero during the cold season (from soil freezing to thawing), and also large burst of methane have been observed during the soil freezing and thawing. Even though, the methane flux during the cold season is small compared to the summer flux, the cold season might cover a large part of the year in high northern latitudes and thus, the cold season emissions might add up and be a significant part of the yearly total emissions. Due to the lack of flux measurement during the cold season, these cold season methane emissions still have high uncertainties.

In this study, we aim to improve our understanding of northern methane emissions during the cold season by utilizing soil Earth Observation and atmospheric methane mole fraction data with an inversion model. The inversion model CarbonTracker Europe – CH_4 (CTE-CH_4) is used to estimate methane fluxes from 2010 onwards by assimilating in-situ measured methane mole fractions including those from the ICOS stations. In addition, the daily SMOS soil freeze/thaw state estimate in the Northern Hemisphere is used to define the extend of the cold season and to constrain prior wetland methane fluxes during the cold seasons.

The evaluation of optimized mole fractions and fluxes against in-situ observations shows that constraining the winter emissions with the SMOS soil F/T data improves model performance, and decreases the annual biospheric emissions from northern high latitudes when compared to the inversion without implementation of the SMOS soil F/T data. This highlights the importance of properly including soil conditions in the modelling of biospheric methane emissions in northern high latitudes.

Nocturnal surface fluxes of N_2O and CH_4 determined from atmospheric measurements at the Cabauw tall tower

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The agricultural emissions of N_2O and CH_4 are the dominant sources in the Netherlands. The study aims to estimate nocturnal surface fluxes of both N_2O and CH_4 using atmospheric measurements at the Cabauw tall tower (4.927◦ E, 51.971◦ N, - 0.7 m a.s.l.). The nocturnal N_2O and CH_4 surface fluxes were derived from the sum of storage and turbulent fluxes. The storage flux was calculated by hourly concentration profiles along the Cabauw tower below 200m from 2016 to 2018, and the turbulent flux was estimated by the Bowen ratio method and only available from April 2017 due to the absence of sensible heat fluxes. For N_2O, we show that a few events occurring between May 30th and June 4th in 2018 dominated the monthly means. Preliminary results show that the average nocturnal surface fluxes are estimated to be 0.31 ± 0.04 nmol/m²/s and 22.44 ± 2.04 nmol/m²/s for N_2O and CH_4, respectively. Furthermore, clear seasonal cycles have been observed for the estimated surface fluxes of both N_2O and CH_4, higher in the summer and lower in the winter. The magnitudes of the seasonal cycles are 0.37 nmol/m²/s and 21.74 nmol/m²/s for N_2O and CH_4, respectively. Moreover, we show that the storage fluxes dominate the total surface fluxes from March to October, accounting for 77% ± 4% and 81% ± 3% for N_2O and CH_4, but the turbulent fluxes prevail during winter months, accounting for 70% ± 3% and 60% ± 10% for N_2O and CH_4.