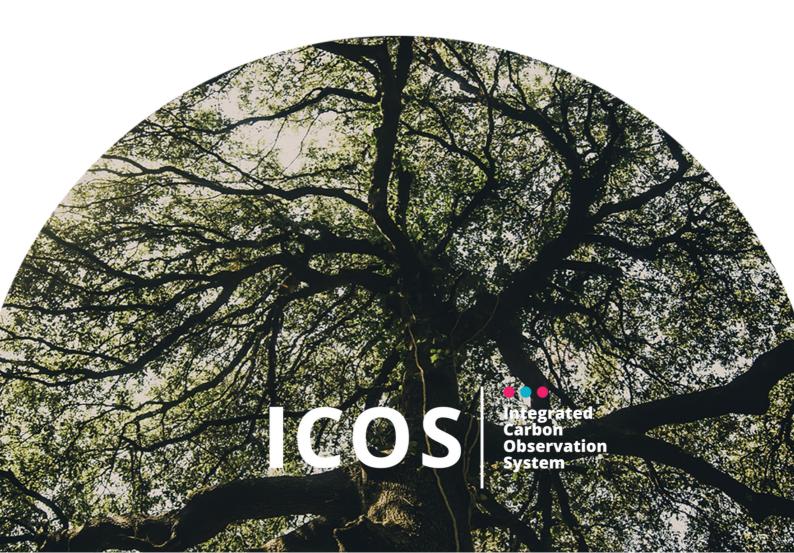
# **ICOS RI Annual Report 2021**

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# **2021 Highlights of ICOS Research Infrastructure**

## **ICOS Cities (PAUL) kicked off**

**PAUL is short for Pilot Application in Urban Landscapes towards integrated city observatories for greenhouse gases -** PAUL was the name of the proposal, but externally we call it **ICOS Cities.** 

This project runs for 4 years, from October 2021 to September 2025. The proposal was accepted with 13.5 /15 points, and the Commission did not want any major changes in the Grant areement phase.

This project supports the European Green Deal by creating capabilities to observe and verify greenhouse gas emissions from densely populated urban areas across Europe. Cities are recognized as important anthropogenic greenhouse gas emission hotspots and therefore play a significant role in any emission reduction efforts. The PAUL project aims to increase our understanding of specific needs of greenhouse gas emission assessment in urban environments; it compares available and novel observational approaches and implements an integrated concept for a city observatory, providing unique data sets that feed diverse modelling approaches, scientific studies and will be the base of services towards the city administrations.

A specifically innovative approach is the co-design of services, models and observations between city administrators and scientists from multiple disciplines including social and governmental sciences. The PAUL co-design approach will explore the needs of the cities and combine these with the scientific outcomes. This allows to introduce smart services to the cities, supporting evidence-based decisions on climate action and strategic investments. Overarching goals of PAUL are to:

- 1. implement elements of a pilot city observatory in a large (Paris), a medium (Munich) and a small (Zurich) European city,
- 2. collaborate with city stakeholders and engage citizens in co-designing services that are required for GHG monitoring in order to validate the implementation of Paris Agreement, and
- 3. increase our understanding of specific needs of GHG assessment in urban environments and create a service portfolio for setting up an urban greenhouse gas observatory."

ICOS Cities external web page: https://www.icos-cp.eu/projects/icos-cities-project

The project kicked off in October 2021. A kick-off event was organized in Paris, allowing remote participation. In addition, a webinar series levelling the background knowledge for partners in this multidisciplinary project has continued through the winter.

## Instrument intercomparison

The 1<sup>st</sup> ICOS OTC pCO2 inter-comparison took place in VLIZ, Belgium. OTC (Tobias Steinhoff) organized the activity and MSA had a significant representation with PIs and the MSA chair (Thanos Gkritzalis) being active in the event. The activity attracted interest from around the world.

## ICOS reference article published in Bull.Am.Met.Soc.

An article describing all three domains of ICOS was published in the online version of Bulletin of American Meteorological Society, one of the journals with highest impact factor in its domain. It is open for all readers and acts as a reference for users of ICOS data.

Heiskanen et al., The Integrated Carbon Observation System in Europe

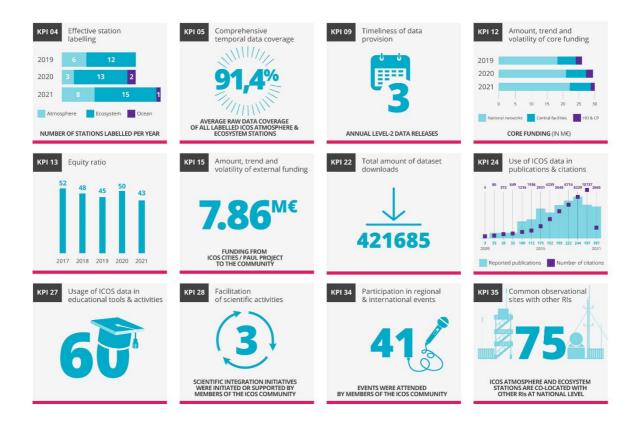
# Coping with the COVID19 pandemic and lockdown effects to operational activities

The COVID19 in Europe affected activities in also during 2021. All European countries experienced periods of distant learning and remote work. Collaboration was done mainly through online meetings.

At the ICOS measurement stations and laboratories these limitations slowed down some activities but did not prevent the work from being done.

## **KPIs summary**

The ICOS Evaluation committee recommended, that 12 of the KPIs are monitored annually. Summary is in infographic below, supported by a longer narrative in the text and annexes. The KPI number is given in the heading.



# **Co-operation with other infrastructures (KPI 35)**

During this reporting period, the lockdowns due to the COVID-19 pandemic have significantly affected the formal cooperation as well as the informal discussions with other research infrastructures.

A working group between the ICOS ERIC Head Office and ACTRIS Head Office preparation team has been established and has compiled a list of synergy topics among which the use of common service providers (e.g. for occupational health, accounting or auditing), the use of common facilities (e.g. meeting rooms, printers) and even the sharing of personnel with specific expertise (e.g. on finances). ACTRIS is expected

to become an ERIC in late 2022. Unfortunately, the differences in maturity are still challenging many practical attempts to cooperate at HO level.

In response to the letter by the eLTER coordination to the ICOS General Assembly on deepening the cooperation (14. GA) three working groups between eLTER and ICOS Ecosystem domain have been established to discuss further discuss synergies. The work comprises station specification and protocols, scientific and technical benefits of co-location and strategic aspects of cooperation (e.g., synergies through inter-RI services). With 32 co-located stations eLTER is the most important RI for ICOS in terms of cooperation at network level. Totally 72 stations are co-located with other ESFRI Roadmap RIs, 28 with ACTRIS and 15 with other RIs such as EMSO and AnaEE. The full list of co-located stations is as Annex 3.

DG acted as Interim Chair of the Board of European Environmental Research Infrastructures (BEERI) as was as such the main contact of the ENVRI community towards ESFRI and European Commission. Further aspects of cooperation with other research infrastructures were:

- On administrational level, experiences were shared in both directions in relation to the EU Joint Research Centre (JRC): ICOS renewed the existing contract; ACTRIS is planning to integrate JRC.
- Highlight of the scientific co-operation has been the parallel preparation and kick off of two EC Green Deal-related Horizon2020 projects: RI URBAN (led by Universities of Barcelona and Helsinki on behalf of ACTRIS) and PAUL (ICOS Cities, led by ICOS ERIC) and the Horizon Europe project KADI coordinated by ICOS, where University of Helsinki (representing eLTER and ACTRIS) and CNRS (representing IAGOS) are beneficiaries. KADI will support African countries to design and implement a research infrastructure on greenhouse gases and short-lived climate forcers. It should be noted that even though the European Commission funds the accepted projects, the preparation of the proposals requires core funding and hence synergies have been achieved here too. Moreover, the cooperation between ICOS, ACTRIS, IAGOS, eLTER and other RIs increases the quality of the proposals and hence the possibility to get funding.
- ICOS also participated in the unsuccessful project proposal ENRISK with several other RIs.
- The existing cooperation in running EU projects was intensified:
  - ENVRIFAIR, EOSC Enhance and EOSC Future enhance the FAIRness of the data and provide a common connection to the European Open Science Cloud. It is intended to implement a common data hub of the environmental domain (ENVRI-HUB) within EOSC.
  - ATMO ACCESS (CNRS and University of Helsinki on behalf of ACTRIS as coordinator, IAGOS and ICOS ERIC as WP leader) develops novel access policies to distributed research infrastructures.
  - ERIC FORUM supports cooperation and knowledge exchange between ERICs and acts as a common voice towards ESFRI or the European Commission.
- Cooperation in Communications: ICOS organised a joint Hackathon in spring 2021 mostly with INAR and ACTRIS, but with other RIs participating as well. The goal was to present the RI data for different user groups, also beyond academia. Furthermore, we organised a staff exchange, where the ACTRIS Communications Officer joined the ICOS Communications Unit (of 4 persons at the time) for a period of two weeks in winter 2021. The purpose was to share experiences, and for the ACTRIS communications person, to learn from the practices of the more established ICOS ERIC. The newest development, in early 2022, was to create a joint group with FMI, ACTRIS, and ICOS communications professionals to share experiences in the field.
- Finnish Ecosystem Science meeting was organized by Helsinki University with ICOS, eLTER and AnaEE research infrastructures. DG gave a keynote talk.

# **Director general and head office**

## **Progress in the regular tasks**

#### **General Assembly coordination**

During the year 2021 ICOS had 3 General Assembly meetings. The extra online meeting related to the ICOS evaluation was in March. All members of Evaluation Committee were invited. Spring meeting 2021 was held online, but the Autumn meeting was finally a hybrid meeting in Copenhagen and 12 delegates of 19 participated remotely. Both Chair and vice-Chair participated physically.

In March meeting the General Assembly took note of the evaluation report as well as the evidence report. The General Assembly also highlighted the priorities based on the recommendations from the report and the lists provided by the Director General.

At the Spring meeting new member of SAB, John Miller was elected. The ICOS ERIC legal entity books 2020 were closed and the financial statements were approved.

No candidates had been nominated for the Chair position, so the chair Jean-Marie Flaud agreed to continue until Spring 2022. The Head Office Work Plan 2022 was approved, but the updates in the Statutes was not approved. The director of Carbon Portal was nominated as a deputy of the Director General during his unexpected absences.

#### **RI** Committee management

The RI Committee, formed by representatives from the Head Office, Carbon Portal, Central facilities and Monitoring Station Assemblies, had 2 online meetings instead the usual face-to-face meetings. Head office hosted monthly teleconferences.

Much of the discussions were related to project calls, how to keep wider community informed about funding opportunities and to find suitable partners. A Discord server was utilized for this purpose. Implementation of recommendations of the Evaluation board was also a topic of long discussions. In addition, the material for GA meetings was discussed and commented., such as raw data policy and station labelling.

#### Support for Scientific and Ethical Advisory Boards

The science advisory board meeting in November was held online and split to two days to accommodate all the various time zones from Finland to West coast USA. The Ethical Advisory Board had 3 online meeting.

In their report, the SAB applauded that ICOS has continued to make great progress in the past year. The SAB commended the several notable enhancements made to the Carbon Portal whereby data usage has increased substantially: Data downloads are up by approximately 50% from 2020 and unique users up by approximately 15%. Notable improvements in the ability to differentiate ICOS from non-ICOS data available via the Carbon Portal has also been impressive. The use of DOIs for datasets has improved the ability to track data usage. The SAB also commends the push for making some near real time data available in the Carbon Portal within 48 hours of collection.

The SAB is excited about the expansion of ICOS, with Spain in 2021, and Hungary in 2022. They also commend the increased interaction among Thematic Centres. The SAB believes the Community Engagement Plan will be a useful document for coordinating the efforts within ICOS. Similarly, the Science Facilitation Plan can be helpful for defining the overall scope of ICOS efforts. The SAB also

supports the idea of a regular State of European Carbon report, but stresses the importance of considering a sustainable scope and frequency of such a report.

#### **Financial management of ICOS ERIC**

The year 2021 was the second year of the second 5-year period of ICOS ERIC. The financial management was not changed since all previous audits were successful and the ICOS Evaluation did not suggest any changes but increasing the visibility of the financial reports. The Annual Contributions of the countries were mainly paid in time, except the Netherlands had difficulties to find the responsible institute for payments. The unpaid contributions have effects to the voting right and ICOS ERIC' cashflow. The Horizon 2020 project RINGO ended during the year and the project was audited by the national auditing company. ICOS ERIC was the coordinator of the project and managed the final payment which was received in November. One new project (PAUL) started with ICOS ERIC as coordinator and the prepayment was received end of 2021 and is currently processed. The Project Manager of PAUL is based at the Carbon Portal at the Lund University.

## Overall financial management of ICOS RI

ICOS ERIC Financial Committee had three meetings during the year. The Chair of the Financial Committee presented the committee's report at the Spring and Autumn General Assembly meeting on the financial situation of ICOS ERIC. The committee has discussed about the financial reports, KPIs and return of the investment. In March meeting the first draft of the cash flow situation has been presented and in April meeting the financial documents for the General Assembly were checked. In October meeting the committee discussed about the sustainable funding and the large share of project funding in total funding. The station-based contribution should be presented at same way divided to the countries in every Central Facilities' budget.

#### Human resources management for ICOS ERIC

During the year, junior controller resigned in March and the new person started at the end of April. A project officer started in April and an observation communications officer started in August. Communication officer resigned at the end 2021 and one of the communication assistants will resign in March. The recruitment process for replacement persons has already been started. The work place survey was completed in May and based on the results, a workshop was given to all personnel facilitated by Occupational Health Psychologist. The work will continue in order to create the Head Office's code of conduct. The Head Office started to plan improvements of the office space, salary structure and career path.

The following personnel was employed by ICOS ERIC: by the end of the 2021 three employees have fixed-term contract until the end of 2022 and rest have contracts until further notice:

- Director General (Werner Kutsch)
- Director of Carbon Portal (Alex Vermeulen)
- Head of Unit I 'Administration' (Anne Malm)
- Head of Unit II 'Operations' (Elena Saltikoff)
- Head of Unit III 'Strategy & International Cooperation' (Emmanuel Salmon)
- Head of Unit IV 'Communications' (Katri Ahlgren)
- Science Integration Officer, Unit II (Sindu Parampil)

- Operations Officer, Unit II (Evi-Carita Riikonen)
- Science Officer, Unit II (Janne-Markus Rintala)
- Communications Assistant, Unit III (Mari Keski-Nisula)
- Senior Officer, Communications (ENVRI-FAIR), Unit III (Magdalena Brus) resigned 31.12.2021
- Executive Assistant, DG Unit (Inka Hellä)
- EU-project Administration Assistant, DG Unit (Leysan Karimova)
- Communications Assistant, Unit III (Karlina Ozolina)
- Senior Officer, Data Analyst, Unit II, (Ville Kasurinen)
- Observation Network Officer, Unit II, (Maiju Tiiri)
- Project Officer, Unit II, (Liisa Ikonen)
- Communications Officer, Unit III (Charlotta Henry)

#### Gender balance

The staff consists of 5 men and 14 women, out of which 3 men and 3 women are in managerial positions. A gender equality plan, as required by European Commission in Horizon Europe projects, is under preparation.

#### **Contract management**

The contract with the joint research consortium (JRC) has been updated for the next four-year period. The General Assemble approved in November meeting the updated Central Facility contracts and mandated the Director General to finalise the signature process by agreeing on final editorial changes with the host institutions when necessary. The legal advisor contract with the University of Helsinki has been resigned and it will end at the end of February. The Audit company was KPMG and junior controller was hired from a staffing company Staffpoint.

#### Operational management of ICOS ERIC and RI (KPI 4)

To support the new countries joining ICOS as well as new PIs for stations, Head Office prepared a brief onboarding document for the ICOS community. This document contains briefings from the Handbook, guidance for FPs and PIs in their role, contact information of TCs, HO and CP as well as links for additional materials. The document was provided to Focal Points as well as new station PIs, and it is also available in Nextcloud.

The information flow between the Head Office, Carbon Portal and Thematic Centres regarding the station metadata was streamlined, and the details of the procedure for adding new stations annually to the network were agreed between the HO, TCs and FPs. The user interfaces in where the station metadata can be accessed were improved: now <u>the station table</u> in the ICOS website collects information coming from both Thematic Centres and Head Office in order to always present the most up-to-date information about station characteristics. New features were added to the table, and now it also has links to the station landing pages for more information as well as listing a labelling date for labelled stations. In addition, some new links were added to <u>the labelling status web page</u> of all stations.

The **Management plan** was further developed as advised by the GA by dividing it in two parts: Concise part I of 20 pages and then more detailed Part II, which contains the detailed task descriptions of various bodies of the RI. The draft was discussed in the November GA, and a separate update meeting was

scheduled for January 2022 to discuss the final comments by some members. The work on the Management Plan simultaneously contributed to the developing of the **Community Engagement Plan**. The framework was discussed in the RICOM virtual face-to-face and presented in the MSA meetings.

In total of 23 stations received an official ICOS label in 2021. Of these stations 7 were atmospheric stations, 15 were ecosystem stations and one was an ocean station. Station contracts were prepared between the ICOS ERIC and the host organisations of labelled stations. Progress of the labelling is illustrated in Table 1 and figure 1, figure 2 and figure 3.

Table 1. Labelled ICOS stations per country, domain and class in February 2022. Note: One ocean station from Germany (DE-SOOP-Polarstern) was labelled as class 2, but has now been changed to class 1.

Status of the ICOS Station Labelling in February 2022																	
Member/		Labelled		Number and type of stations													
Observer	Stations	stations	Ecosystem stations					Atmospheric stations					% Labelled				
countries	total	total	C1	C1 labelled	C2	C2 labelled	Assoc.	Asso. labelled	C1	C1 labelled	C2	C2 labelled	C1	C1 labelled	C2	C2 labelled	per country
Belgium	11	8	1	1	4	3	2	1	0	0	1	1	3	2	0	0	73 %
Czech Rep.	4	2	1	0	1	0	1	1	1	1	0	0	0	0	0	0	50 %
Denmark	10	6	2	2	1	0	6	4	0	0	1	0	0	0	0	0	60 %
Finland	13	11	2	1	2	1	5	5	2	2	2	2	0	0	0	0	85 %
France	22	16	3	2	6	3	8	6	2	2	2	2	1	1	0	0	73 %
Germany	37	20	5	4	0	0	15	4	7	6	5	5	5	0	0	1	54 %
Hungary	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0 %
Italy	17	9	2	1	2	1	6	3	0	0	3	3	1	1	3	0	53 %
Netherlands	3	1	0	0	1	0	0	0	1	0	1	1	0	0	0	0	33 %
Norway	8	5	0	0	1	0	0	0	1	1	1	1	3	2	2	1	63 %
Spain	3	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0 %
Sweden	11	7	0	0	6	4	0	0	3	3	0	0	2	0	0	0	64 %
Switzerland	2	2	1	1	0	0	0	0	1	1	0	0	0	0	0	0	100 %
UK	5	2	1	1	0	0	0	0	0	0	2	1	2	0	0	0	40 %
JRC	2	2	0	0	1	1	0	0	0	0	1	1	0	0	0	0	100 %
Total	149	91	18	13	25	13	43	24	18	16	22	17	18	6	5	2	
% L	abelled per	domain an	d class:	<b>72</b> %		52 %		56 %		89 %		77%		33%		40 %	

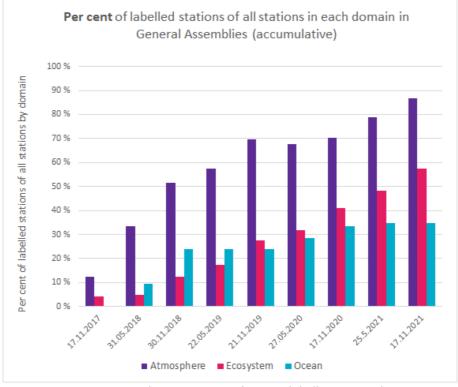


Figure 1. Accumulative progress of station labelling per each GA.

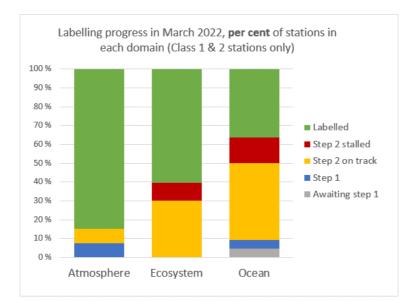


Figure 2. Labelling process, per cent of stations (Class 1 and class 2) in each labelling step by domain.

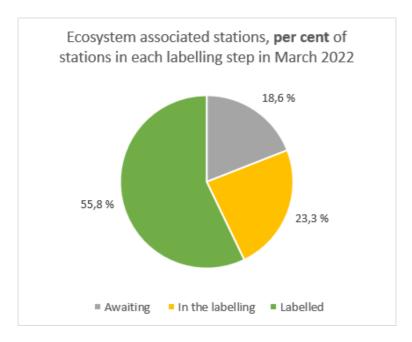


Figure 3. Labelling process of associated ecosystem stations in March 2022.

## Support for ICOS-related science (KPI 28)

In the framework of the Warm Winter 2020 Initiative, the ICOS community directed its efforts in analysing the effects of the exceptionally warm winter of 2019/2020 (followed by COVID lockdowns) on the carbon cycle. Like in the Drought study, the main part consisted of updating the historic time series for the broader network in Europe, in this case, for Ecosystem and Atmosphere (the signals from Ocean data were too weak to study). The work for the atmosphere domain is still ongoing, but recently the work in the ecosystem domain led to the highly-anticipated release of the final updated dataset. The dataset consists eddy covariance fluxes from 73 ecosystem stations, part of them outside the ICOS network, for the period 1989-2020. The data are in the standard format used for the ICOS L2 ecosystem products, which is also used by other regional networks

like AmeriFlux. The data is available through the ICOS Carbon Portal from the Main Data Products page and its DOI landing page where previews and download are available. See <a href="https://doi.org/10.18160/2G60-ZHAK">https://doi.org/10.18160/2G60-ZHAK</a> for more information.

Marie Skłodowska-Curie Action (MSCA) Doctoral Network (DN) training proposal (CarboAdvance) was submitted (as one of 900 proposals) and results are expected in April 2022. The proposal was coordinated by Ivan Mammarella of ICOS Finland and supported by HO. The CarboAdvance consortium comprised of 12 scientists within the ICOS community and aims to 'Advance understanding and predictability of terrestrial and marine ecosystem carbon cycle'. If successful, the MSCA will support 12 PhD positions within ICOS community. The emphasis of MSCA DN is training, hence the consortium will conduct joint events, which will train the next generation of greenhouse gas scientists capitalising on the vast ICOS network and infrastructure. The pan-ICOS proposal aims to train the doctoral students as data users and potential future PIs, capable of effectively bridging the gap between science and policy.

As part of the Science Facilitation Plan (SFP), the HO has started gathering Nationally-funded projects from the ICOS scientists at the request of the ICOS GA. The aim of compiling such a list is so that Pls can learn from the strategies and successes in other National Networks. This would potentially, open opportunities for future collaborations on EU calls and proposals.

Proposal for Horizon Europe project *KADI* - *Knowledge and climate services from an African observation and Data research Infrastructure* was prepared in co-operation with a number of African and European partners. The proposal was successful and project will start in second half of 2022.

See also summary of ongoing projects at end of this report.

## **Communication and community integration**

ICOS can considerably increase its impact to the society of ICOS and its data through outreach and communication. During the year, the Head Office made significant efforts towards that end.

#### External communications and outreach

The ICOS Head Office continued to promote ICOS mission and its services to a wide range of stakeholders. The Covid-19 had already previously turned all communications digital, and this way of operations was continued throughout the year.

To promote the data for new user groups, ICOS produced an Arctic themed online hackathon together with ENVRI community and University of Helsinki Institute for Atmospheric and Earth System Research (INAR). The event gathered over 330 participants from over 30 countries from five continents to produce solutions for tricky environmental challenges. In social media, we received more than 13 000 impressions during that weekend only, with over 100 likes and 50 retweets.

The Head Office produced a digital version of the physical ICOScapes exhibition to the icos-ri.eu website, using an online platform KunstMatrix. At the end of the year, two physical expeditions opened in two nature centres in the Finnish Lapland. All in all, ICOScapes cooperation with the famous photographer Konsta Punkka continued to gain visibility for ICOS in social media. He has sometimes posted ICOS related posts or comments on his Instagram account, and by association, ICOS continues to gain tens of thousands of views and dozens of comments.

#### ICOS materials, website, media and social media

ICOS' external communication activities include production and dissemination of a wide range of engaging content across a variety of channels. The Head Office prepared a publication of a 2022 edition of the ICOS Handbook, to be published early in 2022. The Handbook is widely used and appreciated by the community members as well as by aspiring ICOS countries.

The ICOS data marketing campaign consisting of various pilots proceeded in 2021 with different means. ICOS ERIC produced a 5-minute-long animation video describing the benefits of ICOS to the society. The video was used e.g., in connection with COP24 and in other events. ICOS also successfully piloted marketing its data and studies through Research Gate, the web platform gathering majority of the scientists in the world. Further, ICOS ERIC published 32 pieces of news on its website in 2020 (27 in 2019, 48 in 2020), and sent out 14 newsletters.

In social media, ICOS focuses its efforts on Twitter, Instagram, YouTube and LinkedIn. During 2021, our presence on Twitter, YouTube and LinkedIn has continued to grow. The number of Twitter followers increased by 19%, LinkedIn group by 16% and LinkedIn company page by 62% compared to 2020. The number of Instagram followers has decreased slightly, by 6%, largely due to the fact that ICOScapes campaign has finished. ICOS YouTube channel has gained 24% more subscribers compared to 2020. Additionally, ICOS was mentioned at least 343 times in traditional media outlets in 2021, for example, in relation to Hungary joining ICOS.

Additionally, due to Covid-related restrictions, several events in which ICOS traditionally participates, such as EGU, ICRI and AGU were turned into online events. Consequently, ICOS also turned its participation and booths into digital format.

ICOS ERIC maintains a communications network for the communication officers of the Environmental RIs. The aim is to share the knowledge and best practices as well as news. ICOS was also part of a similar network within other RI clusters.

## **Community integration**

Community integration refers to the RI's ability to include different parts of the RI into activities, the ability to improve activities and respond in an agile way to new opportunities or challenges, and the potential for improving the RI's structure.

ICOS community organised several trainings and workshops to develop things together. Most of those took place in online format.

Besides activities, communication is an important glue fitting the community together. To that end, the Head Office and Carbon Portal regularly supports internal communication activities across the ICOS RI. To enhance cooperation and timely communication across the RI, the HO continued to publish a monthly community newsletter, while the ICOS Carbon Portal maintained internal document management system as well as continued to host an internal discussion forum on Discord platform. The HO also continued the good cooperation with the RI Communications Network in order to align messaging and to share information and best practises.

## International Cooperation

2021 saw the ICOS ERIC family receiving a new member country, Hungary. The formal membership was approved by the General Assembly in May 2021 with an actual start of the membership on January 1<sup>st</sup>, 2022. Hungary was already present in the discussions when ICOS was established as an ERIC and the scientific community, together with the national authorities, showed significant persistence to allow this achievement. Hungary initially brings one station to the ICOS monitoring network: Hegyhátsál, a tall

tower atmosphere class 2 station located near the border with Austria, Croatia and Slovenia, and operated by the Institute for Nuclear Research (ATOMKI). The extension of the geographic coverage towards the Eastern part of Europe is crucial to improve the scientific relevance of the ICOS network. The addition of at least two Hungarian ecosystem stations is planned for the near future. In addition, Spain also officially joined ICOS on 1<sup>st</sup> of January, 2021.

ICOS also had extensive discussions with other candidate countries during 2021, some of them being foreseen to join the ERIC already in 2022. In particular, Ireland, Poland and Romania made significant progress in their national negotiations. New countries also contacted ICOS and expressed their interest for a future membership. This is the case of Slovenia, where co-located stations with eLTER are envisaged, and also of Russia, where greenhouse gas monitoring has recently received increasing attention. In both cases, the contact is established with the scientific communities and the HO has provided information on the formal procedure to join ICOS ERIC.

Cooperation activities with African partners have also taken place in 2021. After the end of the SEACRIFOG project in 2020, ICOS has continued collaboration with the South African Environmental Observation Network (SAEON), who is also a party to the Global Ecological Research Infrastructure (GERI). Both research infrastructures have discussed the ways to implement FAIR data principles in African contexts and transfer knowledge on available and existing technical solutions developed in ICOS ERIC. ICOS also took the lead, together with SAEON and other South African partners, of a proposal that was submitted at the end of 2021 for a Horizon Europe project entitled "Knowledge and Climate Services from an African Observation and Data Research Infrastructure". The project was granted in the beginning of 2022.

After a pause in 2020 due to the pandemic, the conference of Parties to the United Nations Framework Convention on Climate Change (COP26) was organized in Glasgow (UK). ICOS was present and organized a side-event on the Nordic pavilion dedicated to nature-based solutions in the blue economy. Noteworthy discussions were also held with high-level actors in order to advance a common strategy for the global monitoring of ocean carbon (see more details in the Highlights section)..

DG continued the work within the Global Climate Observation System (GCOS) as member of the Terrestrial Observation Panel on Climate. This work is important for ICOS since GCOS is currently updating the implementation plan and refining the essential variables for climate observations. DG also participates in the Group on Earth Observation (GEO) Climate Change working group.

## Green Team

The activity of the Green Team of ICOS ERIC in 2021 was severely disrupted. The continuously evolving regulations regarding remote working profoundly modified the transport habits of the employees for their home-work-home commuting as well as for their business travels. Apart from two events in November/December (the GA organized in Copenhagen and the COP26 meeting in Glasgow), members of ICOS ERIC did not participate in in-person meetings in 2021.

# **Carbon Portal**

## Highlights

- All operational data streams from raw data to elaborated products flowing
- Collaborative Jupyter notebooks picked up by the community
- ICOS CP webinar series
- CoreTrustSeal application

## Data service development

Emphasis of the development of the services has remained to be on stability, user friendliness and performance of the services. In the framework of ENVR-FAIR we implemented a myriad of improvements to make the CP repository even more FAIR. The emphasis of these changes was directed at reproducibility and alignment with the other environmental RIs. Analysis of the FAIRness of ICOS compared to the other RIs in ENVRI-FAIR shows that ICOS relates strongest to all other RIs in the three relevant domains with an overall top in the profile score.

Through 2021 all Thematic Centres released Level 2 data products and as in the last quarter of the year the Ecosystem domain because fully delivering daily NRT data products, now all domains have the operational data delivery fully in place for the labelled stations. The Ecosystem domain now provides two L2 releases per year, by adding at popular request a so-called interim flux data release in the autumn after the end of the growing season. The increase in the number of labelled stations contributed also to the increase in ingested data objects, together with a sharp increase in ingested elaborated products, for example connected to the Warm Winter 2020 initiative.

All CP services have been online in 2021 for more than 99.9% of the time. Short hiccups appeared only due to interruption of the storage services at the trusted repository.

The older server fsicos1, dating from 2014 stopped working and will be replaced in 2022. The new server will take over the tasks of providing a back-up server and to test and stage services before deployment.

Based on user feedback, many improvements, large and small, have been applied to the portal app to improve the user experience, ease of access to the data, previews and the search work flow.

The planned refurbishment of the data usage tracking system, necessary to cope with increased use and download of ICOS data, was successful. To remove from the statistics internal data usage (with CP and between CP and TCs) and to exclude wrongly reporting of data use from bots we implemented filtering of downloads counts based on IP numbers. The statistics app now only shows the external usage statistics. In general, the download numbers are compared to the previously reported counts reduced by a factor of two. The main cause of this reduction is the removal of the downloads by bots. As CP is optimised for machine-to-machine transfer we have to remain careful to not exclude true data use from automated data transfers while trying to remove useless data transfer from the statistics. In the process the user interface for data download statistics at <u>https://data.icos-cp.eu/stats/</u> was improved and extended in functionality.

The exchange of station metadata through the improved mechanisms developed in the framework of the Data Lifecycle Working Group and RINGO became fully operational and resulted in improved data citations, station and instrument landing pages for all labelled stations. Each Thematic Centre developed together with the respective MSAs a scheme for roles at the stations and which roles are reflected in the citations and how these influence the citation order. The metadata flow will be further enhanced by including instrument and provenance metadata.

## Data and data usage statistics (KPI 9, KPI 22)

The number of downloads from Carbon Portal increased further to 421 685 in 2021 (2020: 253 888). The number of downloads of ICOS final quality data (Level 2) and Near Real Time data objects in 2021 was 283 053; in 2020 this was 57 934. The number of Level 2 data downloads in 2021 was 119 946 (2020: 38 667). As can be seen in the right plot of Figure 4, the combined downloads of L1+L2 show clear upward periods just after the L2 releases in spring and autumn 2021.

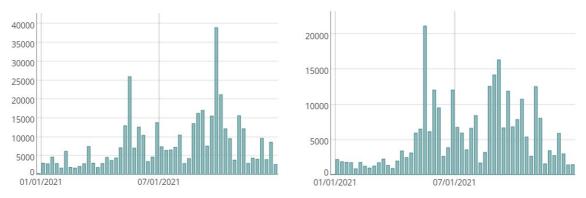


Figure 4. Number of downloads per week of all (left) and L2+NRT (right) data objects at ICOS Carbon Portal during 2021. Peaks in download occur right after important events like for example the Drought-2018 and L2 releases.

Table 2, General overview of website statistics and data repository for the whole year of 2021

Total nr of unique visitors Pageviews Average session duration New sessions	106 975 337 184 1m:57s 67.33%		
Data objects stored			
All 2020 -> 2021	428 976	- >	687 223 (incl. deprecated objects)
All 2020 -> 2021	262 064	- >	406 301
L1 2020 -> 2021	1 022	- >	1 342
L2 2020 -> 2021	214	- >	522
L3 2020 -> 2021	27	- >	92
Data downloads			
All data	421 685		
ICOS Level 1	163		
ICOS Level 2	119	946	
Level 3	35 7	87	
Data access by Python library	24 658		

ICOS Carbon Portal minted 182 DOIs in 2020 (2020: 182), mainly for L2 data products and collections of L2 products. In total now ICOS has minted 433 DOIs, next to 735 000 Handle PIDs.

The geographic spread of downloaders of ICOS data is shown in figure 5. The largest number of users, from the USA, is mainly attributable to downloads of the Global Carbon Project data and the downloads of ICOS atmospheric L2 data in the NOAA Obspack products, that also are registered and counted at Carbon Portal. Similar mechanisms for download usage tracking and citation tracking through ICOS minted DOIs attached to the data are foreseen and agreed upon for ICOS data linked to FLUXNET and SOCAT data products.

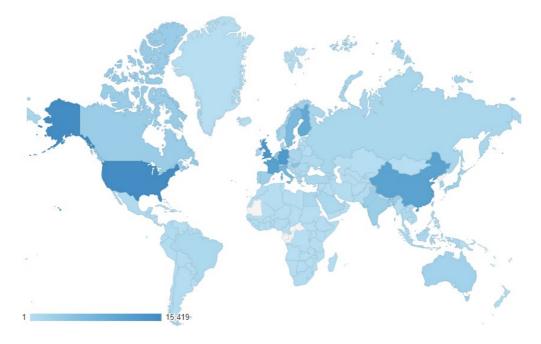


Figure 5. Geographic spread of the ICOS web site users for the year 2020. Biggest number of users is from the USA (10 225), followed by Germany (9 228) and Finland (7 907).



Figure 6. Number of unique users (left axis) and page views (right axis) per week on the ICOS web pages and services in 2021

## Infrastructure support

The Nextcloud fileshare and the integrated document editor OnlyOffice has further gained use by the ICOS community with over 440 active users. The Document Management System Alfresco was already terminated in December 2020 and all documents have been transferred to the Nextcloud system.

The Exchange mail service for ICOS ERIC and the mail lists for the ICOS community were continued throughout the whole year.

The mailing list service has been extended to assist the ERIC Forum project and the ICOS Cities project.

## **Data management and elaborated products**

ICOS Atmosphere released the Level 2 data on 27 May 2021. This full Level 2 2021-1 release of ICOS Atmosphere was released by the Atmosphere Thematic Centre through Carbon Portal for 26 labelled stations and in total 67 vertical levels.

ICOS RI. (2021). *ICOS Atmosphere Release 2021-1 of Level 2 Greenhouse Gas Mole Fractions of CO2, CH4, N2O, CO, meteorology and 14CO2* (Version 1.0). ICOS ERIC - Carbon Portal. <u>https://doi.org/10.18160/WJY7-5D06</u>

On 30 April 2021 a Level 2 release for ICOS Ecosystem for 29 stations has been released:

ICOS RI. (2021). *Ecosystem final quality (L2) product in ETC-Archive format - release 2021-1* (Version 1.0). ICOS ERIC - Carbon Portal. <u>https://doi.org/10.18160/FZMY-PG92</u>

On 30 December 2021 ETC released the interim L2 release for 2021 for 14 stations.

On 27 January ICOS also released the final public release of the observational data from the Warm Winter 2020 Task Force for ecosystem. This data set includes eddy flux data from all 73 stations that participated in this initiative.

Warm Winter 2020 Team, & ICOS Ecosystem Thematic Centre. (2022). Warm Winter 2020 ecosystem eddy covariance flux product for 73 stations in FLUXNET-Archive format—release 2022-1 (Version 1.0). ICOS Carbon Portal. <u>https://doi.org/10.18160/2G60-ZHAK</u>

The next release of a bundled time series data from atmospheric (ICOS and non-ICOS) stations is expected for summer 2022 accompanying the release of the 2022-1 L2 release for ICOS Atmosphere.

The support of regional CO<sub>2</sub> inversions was continued also in 2021, for example for inversions in the framework of the VERIFY project. Updated biospheric model results and anthropogenic emission datasets in high temporal (hourly) and spatial (10km x 10km) resolution were provided at CP as input for regional CO2 inversions.

The Jupyter Notebook services at CP were further upgraded during 2021 and now support also use of the R and Julia programming languages besides the default language Python. The collaborative Jupyter Hub, currently hosting 120 users, now offers advanced options like sharing notebooks and data between users and with the ICOS fileshare (Nextcloud). It allows users to upload own data for analysis together with ICOS data, and provides permanent storage of notebooks and data. This service is continuously expanded in close consultation with our users to support their scientific analysis and interpretation of ICOS data and products.

Easy access to the Jupyter notebooks for exploring and analysing ICOS data for scientific and educational purposes is provided through the public service exploredata.icos-cp.eu service, which does not require registration, offers full functionality of the notebooks, direct read-access to ICOS data but no storage beyond the active session. This service currently allows 60 users to be active at the same time.

An ICOS-specific python library to support easy access to ICOS data in a python programming environment has been expanded and improved and is by default made available in the CP Jupyter Notebook services and also for installation on local computers using the standard 'pip' command. Support for the analysis of STILT model results (atmospheric station footprints and CO2 concentration) was added in 2021.

A series of webinars highlighting the use of the Carbon Portal data app, the ICOS python data access library and the Jupyter notebook services was organised that received a lot of attention from inside and outside the ICOS community. The webinars have been recorded and are available from the ICOS website. A similar webinar was organised as an event during the 2021 ICOS Nordic conference.

The STILT footprint tool and the tool for computing daily updated forecasts of back-trajectories are frequently used by scientists related to ICOS and resulted in 2021 to at least two peer-reviewed articles that made use of the results. Footprint tool results and their further analysis in Jupyter notebooks have provided support for several more scientific publications and presentations.

Support for the dissemination of the FLUXCOM ecosystem flux product was started in 2021 by hosting remote sensing data for FLUXNET sites in the CP repository and providing a Jupyter notebook environment for development of visualization and analysis tools. This contributes to a biospheric model benchmarking chain currently being developed in collaboration between ETC for the flux measurement

data, the FLUXCOM developers (MPI for Biogeochemistry), CP and ModelEvaluation.org in the framework of the CoCO2 project.

#### CoreTrustSeal application

Through the FAIRsFAIR project ICOS 'won' support from this EU project to develop the application for the CoreTrustSeal (CTS) certification of our data repository. CP submitted the CTS application in September 2021 and received the very positive evaluation in January 2022. The final application with the minor comments resolved has been submitted and the certification is expected completed in spring 2022.

## **Training and user support**

As mentioned before in the 2019 report Carbon Portal support was instrumental in supporting the Winter 2020 task force. In 2021 CP curated more data, minted DOIs and collected and organized together with the Thematic Centers the relevant metadata.

The 5th ICOS/RINGO Summer School "Challenges in measurements of greenhouse gases and their interpretation", was after several postponements due to COVID restriction finally held in Hyytiälä from 9-15 December 2021, during a tiny window of opportunity between two waves of COVID. From the original selected 35, only 27 students were able to participate, as candidates from outside the EU could not travel to the EU. Persons unable to attend were mainly from Russia, Ukraine, Belarus and India. The Winter School was however very successful and much appreciated by students with an average appreciation of 5.0 on a scale of 1 to 6.



Figure 7. Participants and teachers of the 2021 ICOS Winter School in Hyytiälä

Training events during which the Exploredata public Jupyter service was used:

- 13 January 2021 ENVRI International Winter School "VREs, Data Analysis & Visualisation" (presenters: Claudio D'Onofrio, Ute Karstens, Karolina Pantazatou, Ida Storm)
- 21 January 2021 INES seminar at Lund University "Jupyter Notebooks in Education examples using ICOS data" (presenter: Karolina Pantazatou)
- 10 March 2021 ICOS Carbon Portal webinar "Introduction to ICOS data" (presenters: Oleg Mirzov, Claudio D'Onofrio)
- 24 March 2021 ICOS Carbon Portal webinar "Notebooks on Exploredata" (presenters: Karolina Pantazatou, Claudio D'Onofrio)
- 12-14 March 2021 Hackathon "Hack the Arctic"
- 19 May 2021 ICOS Carbon Portal webinar "Notebooks for atmospheric stations" (presenters: Ute Karstens, Ida Storm)
- 2 June 2021 ICOS Carbon Portal webinar "In depth: ICOSCP Python Library" (presenter: Claudio D'Onofrio)
- 16 June 2021 ICOS Carbon Portal webinar "Drop-in"
- 25 November 2021 Nordic ICOS "ICOS Carbon Portal & Jupyter notebooks" (presenters: Ida Storm, Claudio D'Onofrio, Harry Lankreijer)
- 8-17 December 2021 ICOS Winter School, Hyytiälä

The ICOS-related educational material produced last year as part of a project collaboration between ICOS CP, ICOS Sweden, Swedish Science Centers (SSC) and Lund University, department of Physical Geography & Ecosystem Science and department of Data Science is accessible online. All science centers and schools have direct access to the educational material, which proved beneficial under the circumstances of the pandemic.

Events and university courses during which the CP educational material and other notebooks on Exploredata were used:

- Lund University, Master's programme in Physical Geography and Ecosystem Science, NGEN16 "Biosphere-atmosphere interactions", autumn 2021 (coordinator: Harry Lankreijer)
- ICOS Winter School, 8-17 December 2021, Hyytiälä

## Management

The Carbon Portal involved in 2021 a team of 18 persons, delivering a total of 15.2 fte, including the external projects (6.5 fte). The overall management, including HR and project management (including acquisition), is performed by the Carbon Portal Director, who is employed by ICOS ERIC. All other CP personnel is employed by either Lund University or Wageningen University.

Just like in 2020, throughout most of the year, the management of CP was heavily influenced and complicated by the limitations imposed by the COVID epidemic, which led to all personnel working mainly from home, and all group meetings took place through online platforms. Internal communication, also with ICOS HO, was enabled use of Slack to the whole team, where before this was only used between the members of the development team. Except for a short period from November until mid-December, all travel and external physical meetings were cancelled and replaced by online meetings.

In regular group meetings, every two weeks, progress is discussed with all CP team members. The CP director also takes part in weekly video conferences with ICOS Head Office and monthly ICOS Head of

Units video conferences. The CP Director and his substitute are also part of ICOS RICOM, that meets during monthly video conferences and two face-to-face meetings every year.

Video conferences with the Thematic Centres have been organised based on emerging needs. Furthermore, the CP director and representatives from CP have been attending the MSA meetings from all ICOS Themes, presenting there the progress at CP and receiving feedback on the developments.

The CP project portfolio in 2021 consisted of eight H2020 projects (PAUL (ICOS Cities), CoCO2, DICE, EOSC FUTURE, EOSC ENHANCE, ATMO ACCESS, VERIFY, ENVRI-FAIR, traceRadon), one Swedish national project (SITES) and one international project (COINS-EEA COPERNICUS). All plenary project meetings related to the CP portfolio projects have been attended by representatives of CP. The EOSC ENHANCE project ended December 2021.

During 2021 CP participated in several new project proposals, at least one project was rejected, all other are still under evaluation.

#### International collaboration/initiatives

Extensive development work for CP is being carried out through EU H2020 and now Horizon Europe projects, that are all beneficial to ICOS with regards to data management and eScience, as well as providing links to EUDAT (CDI) and the other e-infrastructures that will play important roles in the upcoming European Open Science Cloud (EOSC). Maggie Hellström is very active in representing ICOS in several Research Data Alliance working groups, her work in GEDE (Group of European Data Experts in RDA Europe) was laid done to limit the work-load.

CPD is active as chair of the WMO GAW scientific advisory board for greenhouse gases. This year the no 17th WMO GAW Greenhouse Gas Bulletin was composed by the WMO SAG on Greenhouse Gases and coordinated by CP with a good coverage for the ICOS activities in this respect. As always, this edition of the bulletin received a lot of attention in the international press.

CP is also acting as representative of ICOS in the Copernicus COINS in situ project lead by EEA. In a new contract starting March 2021 we will again lead a work package to advertise the CO<sub>2</sub> Monitoring and Verification System with the stakeholders, mainly city and regional representatives.

CD and MH were active as representatives of ENVRI RIs in new EOSC Task Forces on Architecture, and PIDs, with the presentation of white papers on the issues and the initiation of the EOSC Association.

#### **Personnel changes**

Early 2021 Karolina Pantazatou announced that she would leave CP and start as a PhD in the GIS Unit at the INES department of Lund University. After a transition period she transferred to her new job in September 2021. To replace her position as scientific programmer we hired starting July 2021 Zois Zogopoulos. In June Ida Storms, who worked at CP before as student assistant, started as research engineer, she will combine this work with a PhD thesis at Wageningen University on network design, concentration on urban observations. Claudio D 'Onofrio changed position to Senior Reseacher and scientific product developer in March and furthermore to project coordinator of the ICOS Cities project in November. Advertisements for the open positions of a post-doc for working on the DICE project and a software developer were not successful due to lack of good candidates. The search continues, at the start of 2022 CP was heavily understaffed and four positions were open: one post-doc, a software developer and two scientific programmers.

# Projects

## **ATMO ACCESS**

In ATMO ACCESS the atmospheric RIs ACTRIS (coordinator), IAGOS and the atmospheric component of ICOS join forces. The ambition of ATMO ACCESS is to address the needs for developing sustainable solutions based on the principles of open access and to develop guidelines and recommendations for governance, management and funding for efficient and effective access provision suited to distributed atmospheric RIs. This project investigates the most suitable mechanisms that could lead to the sustainable provision of access to atmospheric research infrastructures. Main involvement from the ICOS Carbon Portal is in work package 5, led by CP: Developing and optimally integrating on-line data and computing services, which aims at developing and testing new cross-RI interoperable cloud services in response to specific user needs for innovative tools for data analysis and data management. The work package is divided into three tasks in order to investigate services for different groups, namely:

- 5.1 Homeless data, for long term storage in a FAIR environment, with persistent identification for download, visualisation, and aggregation.
- 5.2 Footprint service, to calculate on demand footprints with the Flexpart and STILT transportmodels, where the results can be retrieved and visualised.
- 5.3 Time series data, provide access to long-term time series from the ACTRIS, IAGOS and ICOS Research Infrastructures with tools for filtering, statistical analysis and interactive visualisations.

Current output of the project consists of a user survey for all three Tasks which was the basis for the deliverable D5.1: Detailed requirements and (non-) technical specifications for all services based on the user consultations. Which contains a detailed system requirement specification and a mock-up for the service implementation.

A second output (Deliverable D5.2) is a first version of Data management plan for data from Trans National Access (TNA) activities.

## CoCO2

The CoCO2 project, coordinated by ECMWF and spanning from 2021 to 2023, will deliver the prototype systems for a new European anthropogenic CO<sub>2</sub> emissions monitoring and verification support capacity that can be implemented within the Copernicus programme. The project is building on heritage of CHE and VERIFY projects. ICOS ERIC is leading WP7 about in-situ measurements, and participating in several others. In 2021, the first deliverable of WP7, *Book of in-situ requirements*, was completed. ICOS CP is also supporting the model evaluation and benchmarking activities in WP4 and WP5 with a collaborative space on the Jupyter Hub and storage capacity on ICOS fileshare.

## **E-SHAPE**

E-SHAPE showcases are operational services in the field of Earth observation research in Europe coordinated by ARMINES, which is this regional GEO initiative aims to improve user uptake of Earth Observation data in the Europe. ICOS HO is coordinating the Global Carbon and Greenhouse Gas Emissions (GCGE) pilot within the Climate Showcase. GCGE pilot in Climate show case is linked to scientific partners from atmospheric, terrestrial and ocean domains that will deliver the methodology used in Climate Show Case Services and demonstrations.

In 2021 the project had its second sprint and first beta version of global terrestrial carbon fluxes is ready. The following step that started in 2021 and will continue during 2022 is the development of pilot services for atmospheric, ecosystem and ocean domain. ICOS ERIC HO also contributed to successful application of a new Climate Pilot partner company Murmuration-SAS that entered to E-shape as new climate related service.

## **ENVRI-FAIR**

#### WP2 - Communication strategies and tools

ICOS ERIC Communications unit is leading the WP2, which has two objectives. The first objective is to facilitate communications of the ENVRI-FAIR project and its results towards and with a wide range of stakeholders using various dissemination, promotion and collaboration techniques. The second objective of WP2 is to further build, engage and promote the ENVRI community to support the implementation of the project results and solutions within the current cluster of Research Infrastructures, as well as outside of it. Moreover, the ENVRI community building activities and tools, such as virtual ENVRI community platform, will also further support the communication, cohesion and harmonisation of the Environmental Research Infrastructure landscape.

# WP5 - Common requirements and testbed for (meta)data services, community standards and cataloguing

ICOS CP has the leading role in the ENVRI-FAIR WP5 and the CP representatives are involved in all WP5 tasks, both at cluster and subdomain level. Since the beginning of the project, monthly virtual meetings are organized by ICOS CP with representatives from most of the project WPs, aiming to regularly report on the project progress and coordinate the tasks among the participating RIs. Additionally, the six (6) cross-domain thematic groups (Task Forces, TFs) that were formed in 2020 (corresponding to commonly identified targets within the ENVRI cluster) continued with their work during 2021, offering recommendations to the participating RIs that helped them improve their FAIRness and update the environmental subdomain implementation plans accordingly. ICOS, having the leading role of WP5, has the responsibility for managing the TFs, following the progress of all groups and reporting back to the community. The CP participates in most of the TF virtual meetings representing ICOS, sharing experience from the portal (e.g. experience reports on triple stores and certification were provided to the respective TF), taking actions for developments that are required by the project (either subdomain or cross-domain requirements, e.g. mapping into DCAT-AP standards) as well as contributing to the harmonization of the different tasks and decision making wherever required.

The year 2021 started with the ENVRI week (online event) where the WP5 leaders organized crossdomain sessions and helped the TFs report their findings to the community. Following this event, and as required by Task 5.3 (led by ICOS), the project participants had to work on a common catalogue of services provided by the ENVRIs. To explore the potential solutions and converge to a common understanding, an online workshop took place in March 2021 where the design of the ENVRI catalogue was discussed with the project partners. ICOS CP contributed not only by organizing the workshop, but also by providing input to one of the demonstrated scenarios of a federated metadata catalogue of datasets. CP representatives also participated in the relevant tutorials that followed, providing ICOS services mapped into the agreed common standards (DCAT-AP) which resulted into a prototype catalogue of services (a proof of concept) where ICOS is present with 4 services. In spring and autumn 2021 a lot of progress was also made on the design of the ENVRI-FAIR demonstrators (i.e. the ENVRI-Hub demonstrators). The ICOS CP contributes significantly to the overall design of the ENVRI-Hub (in close collaboration with the project office) and the development of the ENVRI-Hub pillars, via the contributions to the ENVRI Catalogue of Services as described above, the coordination of the training catalogue component (as a result of the work done by WP6, see below), and the science demonstrators implemented by the subdomains (where ICOS provides services for the WP8, WP9 and WP11 use cases). In November 2021 the WP5 leaders organized one more online 2-day workshop where the RI representatives discussed the harmonisation of the metadata standards, the integration, governance and sustainability of the future ENVRI-Hub and the integration to the EOSC.

ICOS CP members were also included as co-authors in invited talks given by the ENVRI-FAIR project coordinator during the virtual EGU conference 2021 and the AGU Fall Meeting 2021. Another important WP5 activity on which ICOS CP has worked is the construction of an updated FAIR Implementation Profile (FIP) using the FIP tool supported by the project. The results of this process will demonstrate the progress of ICOS in providing more FAIR services since the beginning of the project, as well as the convergence of the ENVRI community at FAIR enabling resources.

## WP6 - Training and capacity building

WP6 is tasked with providing training that will support ENVRI-FAIR project partners, as well as the larger ENVRI Community, in their work to implement FAIR best practices in their data management. ICOS CP leads work package 6, and is in this role responsible for overseeing and coordinating its activities including the creation of training materials, the organisation of training events, and the dissemination of information about such events to the ENVRI Community and beyond. ICOS CP also chairs regular meetings of the WP core group (key persons from ICOS CP and LifeWatch ERIC).

WP6 aims to provide training on a wide range of FAIR-related themes, identified during a knowledge gap analysis performed at the start of the project; this identified 6 topics related to general research data management (RDM) concepts and the FAIR principles, and 22 topics related to core RDM pillars and how to implement these by applying technological solutions and recognized standards. ICOS CP experts have participated in a number of ENVRI-FAIR training sessions, both in a moderator role and as instructors. The latter included a well-attended webinar on how to use Virtual Research Environments (VREs) based on Jupyter Notebooks, presented by Karolina Pantazatou, Claudio D'Onofrio, Ute Karstens and Ida Storm. In addition, Maggie Hellström and Maria Johnsson are actively engaged in a number of RDM training-related working and interest groups under the Research Data Alliance, and have participated (on the behalf of ENVRI-FAIR WP6 and ICOS CP) in several workshops on best practices for teaching FAIR principles, and how to make training materials and events FAIR. Prompted by her engagement with FAIR education in ENVRI-FAIR and at Lund University, Maggie Hellström was invited to co-author a book produced by the FAIRsFAIR project, "How to be FAIR with your data. A teaching and training handbook for higher education institutions".

CP also participates in the subdomain WPs (WP8-Atmosphere, WP9-Marine, WP11-Ecosystem) supporting the ENVRI-FAIR activities (implementation plans, improving FAIRness) of the corresponding thematic centres.

## WP8 – Atmosphere subdomain activities

The Carbon Portal provided a python interface for a specific set of Level 2 data for the domain of atmospheric measurements from the ICOS network. The specification for this interface was developed such that data from all involved Research Infrastructures can be accessed and visualised in a harmonised way. All RI have further mapped their variables and species to the Essential Climate Variables from WMO. Two demonstration implementations are prepared now. One for interactive visualisation of time series, where data from all RI's can be compared directly. The second demonstrator is a co-location service, where a selection of satellite data is available based on temporal and spatial filters.

Further it was decided to map all relevant variables from the RIs to the CF (Climate and Forecast Metadata Conventions) and GCMD (Global Change Master Directory Keywords). For variables not yet described by CF the RI's applications to governing body was provided to enhance the CF Standard Names. This is in progress (the applications where submitted, but the changes in the standard are not active yet).

#### WP11 - Ecosystem subdomain activities

The participants decided to try to harmonise eco system data based on a use case to compare datasets for Soil Water Content. To achieve this all Rl's implemented a translation for their meta data to ISO19139. This results in two metadata records, one for the site (station, platform) description and one to describe the data itself. To reach this goal, the Carbon Portal extended the meta data triple store with individual variables descriptions for ecosystem data. As a side effect now many more (ecosystem) variables can be previewed directly in the data portal. The second work which is still in progress is creating a data pipeline based on a python flask application, to provide a general applicable approach to 'export' meta data for ICOS data objects as ISO19130 conform xml files.

## **EOSC ENHANCE**

CPD represents the ENVRI-FAIR project to follow the further development and specification of the EOSC Portal together with representation of the other ESFRI science cluster projects. This project is an intermediate and short-term project to fill the gap to the start of the EOSC Future project that is supposed to begin mid-2021 and that will further operationalise the EOSC system. Important developments, specifications and requirements, for example on the on-boarding process for services in to the EOSC Portal and the development of metadata standards for describing services and data are fed back into ENVRIFAIR through its WP5.

## **EOSC FUTURE**

EOSC FUTURE is a follow-up program on EOSC ENHANCE and other EOSC related programs to further develop the EOSC Portal. The project started April 2021 and is coordinated by Technopolis. As the commission was not happy with the Grant Agreement, about 6 months of negotiations were needed to arrive at an improved Grant Agreement and a new coordinating team. In the project a part of the budget is allocated for so called science projects, in which the Science Cluster have been tasked with providing applications where they demonstrate the use of EOSC e-infrastructure resources to provide meaningful scientific products that can be served through the EOSC portal. ICOS is coordinating an ENVRI community Science Project called "Dashboard of the state of the environment". ICOS is also involved in the WP on training, focussing on developing training and learning resources targeting EOSC (data) service providers,

## ERIC FORUM

In the ERIC Forum project, ICOS ERIC participated in discussions about the ways to measure and convey the socio-economic impact of ERICs, provides the project website and email lists, and continued to develop an online toolbox which will gather the results of the project to a user-friendly format: the purpose is to allow RIs to benefit from the joint knowledge gathered there, and to facilitate the process of becoming an ERIC.

## **ICOS Cities (formerly known as PAUL)**

ICOS-lead proposal to the EC Green Deal call of Urban observatories was successful and the project kicked off in October 2021. See highlights for more.

## **RI TRAIN Plus**

Building of heritage of earlier project RITRAIN, RItrainPlus project will transform the skills-base to drive the professionalisation, efficiency and long-term value creation of European Research Infrastructures and Core Facilities. This Project brings together, for the first time, research infrastructures, core facilities, business management Schools and European universities, in a new innovative concept to transform the access and empowerment of human resources for national and international scientific facilities in Europe.

ICOS ERIC contributes to the RITRAIN Plus -project by participating in work packages that focus on the development of common European policies and learning tracks for curricula enrichment and development, course development and delivery (where ICOS ERIC is involved in developing a module relate to the socio-economic impact of RIs), staff and knowledge exchange programme within European RIs, CFs and abroad, design study of a European School for Management of RIs, and communication and outreach (where ICOS ERIC is leading the work package).'

## SITES

ICOS CP continued hosting and developing the SITES data services. Metadata was defined for the main thematic programs (Station base data, SITES Water, SITES Spectral, and SITES AquaNet) which enabled stations to upload the first quality checked data. SITES applied and was granted another period of funding and the cooperation between ICOS CP and SITES has been extended until 2028.

## traceRadon

ICOS CP contributes to the (EMPIR) 19ENV01 project traceRadon with the development and evaluation of a radon flux map as service for atmospheric transport model evaluation as well as for radiation protection applications (WP3 led by Ute Karstens). The main goal of the project is to establish metrological traceability for low-level outdoor radon activity concentrations measurements (a recommended measurement parameter at ICOS atmosphere stations) and radon flux measurements. The process-based radon flux map for Europe was updated using state of the art soil moisture reanalyses and the latest version of the European soil uranium content map. Evaluation of soil moisture reanalyses as well as resulting radon fluxes is ongoing.

## VERIFY

The aim of the H2020 VERIFY project is to develop a pre-operational system to estimate greenhouse gas (GHG) budgets and support countries in their reporting tasks to the UN Framework Convention on Climate Change. The main role of ICOS in the project is to contribute to the communication of the project and the dissemination of its results. Due to the COVID pandemic, many events were postponed and the project has applied for extension.

ICOS has an important role in the in situ component of the new architecture envisaged by the European Commission for a Monitoring and Verification Support (MVS) Capacity. This endeavour will be built on the results of VERIFY and the other related H2020 project CHE, and it is further developed in the follow-up project CoCO2, starting in 2021.

# **Atmosphere Thematic Centre (ATC)**

## Highlights

- Implementation for the whole ICOS Atmosphere dataset, of the international CO2 scale change from WMO
- Demonstration of sub ppm precision for mid-cost CO2 sensor for urban applications
- New processing chain for the new technological instrument FTIR that measure at once CO2, CH4, N2O, CO, CO2 isotopes

## Data collection and availability (Task 1)

#### Level 0 data transfer (Task 1.1)

New station and instrument registrations took place and new data transfers have started.

- The German Zugspitze station has started to transfer GHG data and meteorological data.
- The German Westerland station has started to transfer GHG data and meteorological data.
- The German Schauinsland station has started to transfer GHG data and meteorological data.
- Beginning of the automatic processing of the English Weybourne station FTIR data.

#### Maintenance

- Maintenance of the network data.
- Manage multiple instrument movements on different sites as well as change of processing parameters.

#### Developments

- The weekly GHG data reports for the PIs have been enhanced.
- Improve traceability of automatic processing warning and errors by adding more information in the database. This information being structured will more easily be used to analyze the data and generate reports.
- Update of the processing chain which process FTIR data the newly accepted ICOS Atmsophere instrument
- Update of the Picarro processing chain, the corrected water vapor is now computed and stored along with the raw data and all the data of the database have been updated.
- Implementation of a new Spike detection algorithm (REBS). The algorithm is currently under evaluation by a working group.
- Evolutions on the role system.
- Update of the metadata processing chain which can now automatically process metdata from the ATC meteorological lab. Evolutions have also been made to the data accessible from the command line.
- Update of the metadata automatically sent to the Carbon Portal along with the NRT data.
- Evolution of the graphical applications:
  - $\circ$   $\;$  Add the possibility to configure FTIRs in the ATCConfig.
  - Updates and new functionalities added to the ATCQc (display of data from multiple instruments per site, from multiple sites, display of air mass classifications)
- extensive preparatory work for the international CO2 scale update

#### NRT data production (Task 1.2)

A total of 38 (+1 compared to 2020) stations are connected to ATC, sending their data to ATC and, consequently, are able to be processed in NRT mode. This represents 15541 (+22% compared to2020) raw archive files (~106Go, +2.4% compared to 2020, for a mean of 7.6Mo/station/day) processed for an availability rate of ~0.99 (+0.01 compared to 2019) for 35 (+6 stations compared to 2020) stations which transmit their data over the complete 2021 year.

ATC has developed an advanced standalone sequencer to control the gas sampling and distribution system upstream the GHG analyzer. The sequencer is able to schedule complex sequences using loops, based on duration and/or time (able to schedule a vertical profile on tall tower at key periods of the day, automatic shelter tests every month for instance). The sequencer is able to manage the related configuration (tank connection, sequence declaration) on the ICOS server. Finally, this new tool allows to sync the sampling of the GHG analyzer with the ICOS flask sampler thanks to a TCP/IP protocol and a task priority management. The ATC sequencer is now available for the ICOS community.

#### NRT data visualization and distribution (Task 1.3)

NRT data visualisation can be accessed on ICOS ATC website [<u>https://icos-atc.lsce.ipsl.fr/dp</u>], through the page of the NRT data products generated at ICOS ATC, and/or, depending on the product, directly on the panel board of the concerned station (accessible via its trigram code).

In 2021, 57 families of graphical NRT Data Products, (~ 2955 products in total, which represent a decrease of -50%/2020, for ICOS network stations) are produced daily from NRT measurements (total volume of 740Mo (-0.26Go/2020) and freely available on the ATC website for station monitoring and diagnosis. The decrease in volume and number of products is mainly due to a to a cleaning of the tree structure which allowed the removal of products associated with instruments that were no longer operationnal in the station, and therefore obsolete

Those Data Products are for PIs to verify the status of their stations. In total, for the year 2020, nearly  $\sim$  3,024 (-8.7%/2020) users have interacted with ATC's website, for  $\sim$  41,599 (+3.88%/2020) page views.

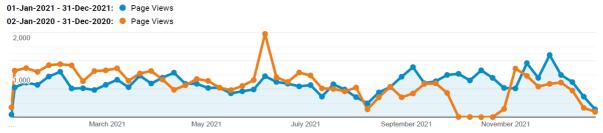


Figure 8. Page views for 2021 (in blue), compared to 2020. (Spike in June 2020 is for Atmosphere MSA)

#### Level 2 data production (Task 1.4)

The new Level 2 (2021-1 release final quality controlled observational) data from the atmospheric network has been released on September 2021 by the ICOS Atmosphere Thematic Centre. This 2021-1 release containing data from the atmospheric network of ICOS Research Infrastructure for 26 stations and 67 vertical levels at Gartow, Helgoland, Hohenpeißenberg, Hyltemossa, Ispra, Jungfraujoch, Karlsruhe (KIT), Křešín u Pacova, La Réunion, Lampedusa, Lindenberg, Lutjewad, Monte Cimone, Norunda, OPE, Ochsenkopf, Pallas, Puy de Dome, Saclay, SMEAR-II Hyytiälä, Steinkimmen, Svartberget, Torfhaus, Trainou, Utö - Baltic Sea and Zeppelin Observatory. This collection contains the final quality controlled hourly averaged data for the mole fractions of CO2, CH4, N2O, CO and meteorological

observations measured at the relevant vertical levels of the measurement's stations, also available 14C in CO2 in two-weekly integrated samples, for the period September 2015-January 2021. All stations follow the ICOS Atmospheric Station specification V2.0 (doi:10.18160/GK28-2188) and are certified as ICOS atmospheric stations Class I or II. Data processing has been performed as described in Hazan et al., 2016 (doi:10.5194/amt-9-4719-2016).

## Network coordination, training and development (Task 2)

## Instrument testing (Task 2.1)

Even though the COVID-19 was still impacting significantly the work conditions in 2021, the ATC Metrology Lab (MLab) has kept a regular workplan with limited restrictions. Indeed, ATC Mlab has performed all the instrument testing required for the station labelling, including: leakage rate, instrument precision, linearity and drift, short term and long-term repeatability, sensitivity to inlet pressure, atmospheric pressure and temperature, H2O correction. ATC has provided test report and a certificate of compliance to all the instrument tested. Moreover, ATC Mlab has performed technology watch activities with few new analyzer testing. Indeed, the Mlab has tested the new N2O analyzer LI-7820 from LICOR using the OF-CEAS technology. Moreover, the latest version of the Picarro Gasscouter (G4301) has been evaluated in the ATC facilities. End of 2021, ATC Mlab start the assessment of a multispecies QCL spectrometer from MIRO able to measure GHG (CO2, CH4, N2O, H2O) and Air Quality compounds (NO, NO2, O3, CO, NH3). The performance will be presented during the next MSA.

ATC MLab has finalized the study artifact with stainless steel tubing as few ICOS station sampling system tests performed in the field (SAC, TRN) have shown significant bias on CO2 related to this type of tubing. The related requirement is to avoid the use of stainless-steel tubing when the humidity of the air sample change (e.g., tubing downstream the Valco while the ambient is not dried with a cryogenic water trap). ATC has provided the corresponding recommendation during the first MSA in 2021. The new release of the ICOS specifications (scheduled in 2022) will include the corresponding recommendation.

Further to water vapor correction determination and application issue observed on 2 ICOS sites in 2021, ATC has improved its internal quality control procedure in order to avoid such issue. Indeed, ATC Mlab has implemented additional quality control tools and internal data products as well as an automatic data processing chain interfaced with the ICOS data base and the WebObs tools in order to automatically process (with automatic QC) the data related to a water vapor correction assessment test performed in the field and declared by the station PI on the WebObs interface. The corresponding test report automatically generated, once controlled and validated by ATC is then pushed to the ICOS data base to be archived and to update the corresponding coefficients.

Once the stations are labelled, ATC carry on controlling the quality of the data provided by the station by checking the corresponding ATC data product in interaction with the station PIs.

ATC is still working on performance testing and characterization of several mid and low-mid cost sensors for  $CO_2$  and  $CH_4$  like MirSense MultiSense photoacoustic sensor, Senseair HPP and K96, Vaisala GMP343, Figaro CH4 Metal Oxide sensor... This prospective work takes place for new domain of application (mobile measurement, dense low-cost sensor network for urban area or industrial site...). This testing is the first step preparing ICOS-Cities-PAUL focusing on CO2 emission in 3 urban areas: Paris, Munich and Zurich.

## Atmospheric station audit (Task 2.2)

ICOS Mobile Laboratory is one of the subunits of the ICOS RI Atmosphere Thematic Centre (ATC). It is physically located in the Finnish Meteorological Institute and mainly funded by the Ministry of Transport

and Communication in Finland. The main task is to conduct quality control (QC) by parallel measurements at atmospheric stations (AS).

Manpower for running the Mobile Laboratory is planned to be two full-time persons. The Mobile Laboratory has a fully equipped van, which can be used for parallel measurements. The instrumentation of the Mobile Laboratory includes at the moment a Picarro G2401 (CO<sub>2</sub>, CH<sub>4</sub>, CO), a Picarro G5310 (CO & N<sub>2</sub>O) and an Ecotech FTIR (CO<sub>2</sub>, CH<sub>4</sub>, CO, N<sub>2</sub>O). End of the year 2021, the Picarro G5310 was sent to repair due lowered measurement frequency and the calibration cylinder set was recalibrated at CAL-FCL.

Due Covid-restrictions for travelling, the MobileLab performed two audits in Finland. Level 1 atmosphere station Pallas (PAL) was audited in early spring 2021 and the audit report finalised in autumn 2021. During PAL audit, the MobileLab helped for Pallas GAW station audit performed simultaneously. In autumn 2021, level 2 station Puijo (PUI) was audited, and the report is under preparation.

As a part of QC procedures of the Mobile Laboratory, it monitors calibration scales between ICOS CAL and Mobile Laboratory, using travelling cylinders prepared by WMO/GAW Central Calibration Laboratory.

#### Training activities for ICOS atmospheric measurements (Task 2.3)

Due to the Covid-19 context, ATC has organized one online training. The attendees of this training were Pls/Staff from Germany, Italy, UK and Spain. It was over 3 days.

All the initial training requested for new ICOS comers and step 2 labelling have been provided by ATC.

ATC will continue to offer standard training at ATC in order to answer the demand of new incomers and also to deal with the technical staff turnover. These standard training might be online and face-to-face meeting at LSCE (more suitable for experimental practical work). In addition, ATC is working on Webinar dedicated to new specific topics (instrumentation, sampling setup) and refresh on topics already dispensed in the initial training session in order to maintain atmospheric station staff well trained and achieve the best data quality within the European ICOS network. During the last MSA, an ICOS survey point out the need of a webinar on the WebObs tools which is now required to interact with ATC for the shelter and droplet test (every year). The first webinar in 2022 should thus focus on Webobs presentation and good practice. a second webinar will focus on data quality control and new features on ATC QC tools.

#### Activities and plan reported to the DG, RI Com and General Assembly (Task 2.4)

The ATC workplan, reports and associated budgets were provided to ICOS HO. The ATC attended both General Assemblies that took place in 2021 as well as the two RICOM face to face meetings. Station labelling process, Steps 1 and 2 (Task 2.5). Labelling of 8 new ICOS Atmosphere stations in 2020:

## Significant publications in 2021

Yver-Kwok, C., Philippon, C., Bergamaschi, P., Biermann, T., Calzolari, F., Chen, H., Conil, S., Cristofanelli, P., Delmotte, M., Hatakka, J., Heliasz, M., Hermansen, O., Komínková, K., Kubistin, D., Kumps, N., Laurent, O., Laurila, T., Lehner, I., Levula, J., Lindauer, M., Lopez, M., Mammarella, I., Manca, G., Marklund, P., Metzger, J.-M., Mölder, M., Platt, S. M., Ramonet, M., Rivier, L., Scheeren, B., Sha, M. K., Smith, P., Steinbacher, M., Vítková, G., and Wyss, S.: Evaluation and optimization of ICOS atmosphere station data as part of the labeling process, Atmos. Meas. Tech., 14, 89–116, https://doi.org/10.5194/amt-14-89-2021, 2021.

# **Ecosystem Thematic Centre (ETC)**

## Highlights

- Near Real Time data operational
- Interim Level2 production
- Warm Winter 2020 collection release

## Data collection and availability (Task 1)

The data collection is now a systematic and robust task that continues each year including new stations and involving both ETC and Carbon Portal. All the labelled stations and the stations under labelling procedure submitted data and metadata. Vegetation samples and soil samples have been shipped by respectively 46 and 3 stations to the ETC labs in France for the analysis (27 and 3 respectively in 2020).

Level2 data have been produced and distributed through the CP, including this year for the first time, in order to follow an explicit request of the MSA, an Interim version released after the growing season. For the first year also the Near Real Time data production and release started operationally and the data released cover the period from the last Level2 release to the current day.

#### Raw data transfer (Task 1.1)

The raw data flow from the station to the Carbon portal continued regularly under the supervision of the ETC. The metadata needed to interpret and then accept the files submitted are transferred regularly to the Carbon Portal in a machine to machine procedure. Also, the ancillary raw data, in particular the DHP and ceptometer files have been regularly submitted to the ETC portal and transferred to the Carbon Portal where they are archived and assigned a PID. There have been more than 1242 vegetation samples shipped to the ETC (they were 671 in 2018, 934 in 2019 and 989 in 2020) for the analysis and 78% of the samples have been already analysed and imported in the database. In addition, more than 570 soil samples have been shipped for analysis in 2020 and are under processing with 394 already analysed. The soil samples are stored in the long-term facility for 12 sites.

## NRT data production (Task 1.2)

Near Real Time are produced every day and transferred to the Carbon Portal. The processing, scheduled every morning at 7AM, after the check of raw data completeness and coherence with the metadata (that generates alert messages to the Station Teams for rapid intervention), produces a number of results that are uploaded to the Carbon portal. Among the different products there is also a new file (AUX) for the auxiliary data provided by the eddy covariance sensors that can be important for an early detection of issues with the different sensors. The NRT results are cumulative, with every day the addition of 48 half hours, and they start the day after the release of the Level2.

## NRT data visualisation and distribution (Task 1.3)

As already reported in the past years the visualisation and distribution is happening at the Carbon Portal. The ETC and the CP collaborated in designing and selecting the variables to plot and the set of files to distribute (see Level2 production).

#### Level 2 data production (Task 1.4)

The Level2 data production and upload to the Carbon portal happened for the first time twice in the year. Following a request from the MSA, supported also by the GA, a second processing period has been defined at the end of the growing season for both the continuous (fluxes and meteo) and ancillary data. The product, named Level2 Interim, deprecates the official Level2 released in spring, and it is deprecated by the new official Level2.

Also, the organisation of the Level2 product has been completely revised and optimised. Five different continuous half hourly files are now produced (FLUXES with the eddy covariance flux data, METEOSENS with the single sensors meteo measurements, METEO with spatial averages and aggregations of the meteorological sensors, AUXDATA with variables to evaluate the status and performances of the sensors and FLUXNET with the gapfilled and partitioned fluxes, in agreement with the international standards). In addition, three metadata files are produced, INST with the information about all the sensors, SITEINFO with all the general station information and ANCILLARY that includes all the results of all the ancillary data measured and processed (by the ETC or by the station teams), in a format that is fully compliant with other international networks. All these files are also available in the most complete product (ARCHIVE) that also includes temporal aggregations of the FLUXNET product and few additional metadata. In this way we think that we serve all the data in a hierarchical system (from single sensors to general aggregated and gapfilled) that will serve all the possible users.

Soil carbon and nitrogen stocks calculations are now operational for the mineral soils. They are under validation with the site's PIs. The organic part of the soils is currently being analysed for 4 sites. This analysis has required buying a new grinder for organic material by the soil analysis laboratory to cope with the samples sent. The soil carbon and nitrogen stocks calculation for the organic horizons has been prepared and will be tested as soon as the analysis is done. A comparison with soil stocks measured during previous soil sampling campaigns is being prepared by ETC for the sites where this information is available.

## Network coordination, training and development (Task 2)

## Training and information of the ICOS ecosystem network (Task 2.1)

Eight Instruction documents have been revised, clarified and updated in 2021, and 19 BADM templates for the ancillary data revised and improved, in particular to collect in the best way the metadata needed to improve the data documentation and FAIRness and the transfer to the CP like for example more precise information about the use of magnetic or geographic North needed for the sensor location description. The list of the sensors listed in the ETC and with a unique identifier arrived at 327 models.

The ETC coordinated an activity for the evaluation of a different method for the GAI measurement using below canopy PAR sensors under canopy. The field campaigns done in coordination with the PIs of the ICOS stations provided a dataset that has been used as the basis for the first version of the new Instruction currently under the review of the MSA.

A new instruction document for ancillary data collection for shrublands was developed, including several field campaigns to validate the indirect measurements techniques of GAI and AGB with destructive measurements.

## Activities and plan reported to the DG, RI Com and General Assembly (Task 2.2)

The activity and financial plan for the 2022 and the report of the 2020 activities (including the financial report) have been prepared and submitted to the DG and HO using the agreed template and guidelines approved by the GA.

ETC participated to the spring and fall GAs presenting the results obtained and the situation of the activities, to the meeting of the Advisory Board and to the Evaluation process meetings. ETC participated to the RICom meetings and teleconferences

#### Station labelling process, Steps 1 and 2 (Task 2.3)

The activities on the labelling continued in 2020 with stations that entered the process and stations proposed for labelling. In particular:

- Six stations started the labelling procedure (CD-Ygb, DE-Har, DK-RWC, GL-NuF, IT-Niv and SE-Myc)
- One Class2 station completed the Step1 and started the Step2 (SE-Myc)
- Fifteen stations completed the labelling in 2021: 3 Class1 (DK-Sor, IT-Cp2 and UK-AMo), 3 Class2 (FR-Gri, FR-Pue and IT-Ren) and 9 Associated (CZ-wet, DE-RuR, DK-Gds, DK-Skj, FI-Ken, FR-Tou, GL-Dsk, GL-NuF and IT-BFt)
- All the Class1 and 2 proposed passed the Step1 and 17 are in the Step2 with different levels of advancement.

## **Other important activities**

In 2021 the Warm Winter 2020 collection of eddy covariance measurements has been released. The ETC collected, quality checked and processed using the standard pipelines (used also for the Level2 FLUXNET product) data from 73 stations, 49 of these from ICOS.

In 2021, soil texture was included in the BADM so that each site can report a measured soil texture and alternatively soil texture was proposed as an additional measurement that can be proposed by the soil analysis laboratory. For this, 15 samples from 5 depths and three SPI will be selected out of the samples used for bulk density to be sent to the laboratory. The service is fully supported (financially) by the ETC.

# **Ocean Thematic Centre (OTC)**

## Highlights

- Managing the Instrument intercomparison in middle of COVID
- 25 certified calibration gases delivered to Stations ensures transparent calibration of CO2 measuring equipment within ICOS.
- Twice a year station 'Ring Arounds' in the Ocean community continued

## Leadership and Management

The OTC is engaged in a wide variety of international activities on behalf of the stations, summarised below. The general aim is to raise awareness of the need to keep supporting ocean carbon observations

and to attempt to raise funds to support stations in a more sustainable way. Our major action last year was the JPI Oceans one, ICOS stations are now firmly embedded in this process and we are optimistic that it will act as a good way to bring the community together to deliver exciting regional and continental scale science based on the ICOS station network

International Action	OTC Action
IOCR Report and Meeting in late 2019	Keynote talk given by sanders, substantial contributions to final report in 2021 around observing system design and resilience
G7 Statements around the Future of the Seas and Oceans 2021	Engagement of co-Director Andrew Watson (UK) in G7 Meeting, engagement of Richard Sanders (No) in drafting briefing document for G7
IOCCP surface pCO2 observing working group	Engagement of Richard Sanders and Siv Lauvset in working group formation. This builds on the SOCONET (Surface Ocean CO2 NETwork) initiative the global ocean surface ocean CO2 observing network.
JPI Action on Ocean Carbon Capacities, large scale potential programme across Europe focused on closing key knowledge gaps	Launched by JPI in 2021 in response to Submission by Sanders and Sandquist in late 2020. Now considering actions in 7 separate areas, with three being lead by ICOS PIS and two more having heavy involvement of ICOS stations
NACO, Canadian Initiative on North Atlantic Carbon Observatory	Engagement of Andrew Watson in steering group, Sanders invited to give keynote talk at Scoping meeting December 2021
IOCOS; Integrated Ocean carbon observing system. Umbrella group launched in summer 2020 after ICOS Townhall in San Diego in March 2021 bringing together international effort in ocean carbon observing	Initiated by Sanders at Ocean Sciences, submitted to UN Decade as programme, now invited to become an exemplar within the UN Decade for Ocean Sciences

List of abbreviations

IOCR - Integrated Ocean Carbon Research IOCCP - International Ocean Carbon Coordination project JPI - Joint programming Initiative NACO - North Atlantic Carbon Observatory

## Labelling

In 2021, OTC worked with multiple stations to help complete the requirements for the labelling process. Also, during this year, Covid restrictions delayed the station activity at some location. The Belgium SOOP line Simon Stevin (BE-SOOP Simon Stevin) completed the labelling procedure and was accepted as an ICOS station Class 1, while other stations received help to improve the measurement setup or to organise discrete validation samples. The labelling procedure was slightly revised and is available (together with older versions) at the OTC web page. In 2021, OTC continued post processing the data collected during the saildrone mission, and furthermore, a technical report was prepared and sent to the drone company. The saildrone mission, which was sponsored by external funding, tested if unmanned vehicles could be used to in-situ validate station data.

## **Training and Station support**

**Gas bottle calibration scheme:** In 2020 the OTC started together with the ICOS flask and calibration laboratory in Jena/Germany a support scheme for the ocean community. In 2021 the first certified (WMO traceable) gas bottles were delivered to stations. By the end of 2021 more than 25 bottles were send to the community. This ensures transparent calibration of CO2 measuring equipment within ICOS.

**Sub-standard preparation:** Due to the pandemic, the supply of Certified Reference Material (CRM) for measurements of inorganic carbon variables that is supplied by the laboratory of Andrew Dickson in La Jolla, California/USA stopped completely. This became a huge problem for marine carbon laboratories all around the world. In collaboration with GEOMAR Helmholtz Cetre for Ocean Research Kiel in Kiel/Germany the IOCS OTC prepared more than 400 bottles (500 and 250 mL) of a sub-standard based on seawater from the North Atlantic Ocean. The bottles were distributed to ICOS labs to guarantee their operation.

**pCO<sub>2</sub> intercomparison**: The major activity undertaken in 2021 was the delivery of the pCO<sub>2</sub> intercomparison activity at the Flanders Marine Institute (VLIZ) in Ostend/Belgium lead by Tobias Steinhoff This was conceived as a once in ten years landmark calibration activity which we believe will set a benchmark for ocean pCO<sub>2</sub> observing system. Originally planned for 2020 this was delayed until 2021 for Covid related reasons and then run with a very reduced core set of staff. The inter-comparison ran over two weeks with an additional week for setting up the instruments. In total 29 instruments (18 different types of instruments) participated in the experiment. They were divided in three categories: (i) underway (flow-through) applications, (ii) surface (e.g., buoy) applications and (III) submersible (e.g. moorings) application. However, the experiment was limited to surface application since all instruments were set up in a temperature controlled 5 m<sup>3</sup> tank or were supplied with seawater from the tank. Temperature in the tank varied between 10 and 30 °C and the pCO2 values between 250 and 800 µatm. The results were discussed with interested scientist during daily virtual meetings and generated strong international interest via its partnership with IOCCP. The publication of the results is planned for summer 2022.

## Data

The OTC Data group focusses on developing tools to help stations QC their data and submit it to international repositories as well as assisting with the submission process. The data lifecycle within the ICOS RI incl. OTC has many steps, including transmissions of data and metadata between the PIs, the TCs, and the Carbon Portal. The steps include different levels of quality assurance and control, version control, standardized vocabularies, data archiving, assigning of persistent digital identifiers, and data publications. A web-based tool (QUINCE) has been developed and deployed to facilitate the entire data pipeline from data collection at the sensor until final publication, using standardized processing

algorithms, automated and manual quality control, and automated publication. Full provenance records are kept for all processing steps allowing transparent tracking of all procedures applied. ICOS OTC implemented a version control system so that older versions of the data can be restored if needed (including raw data availability). The OTC follows international procedures and best practices for the above steps. 15,923 downloads ware recorded for all OTC data in 2021.In addition, ocean data are integrated into SOCAT (http://www.socat.info) for higher level usage e.g., annual Global Carbon Budgets.

## Technology

The major activity in 2021 was preparing a large proposal to the EU for submission in early 2022 around technical innovations to support the Network. This is in collaboration with EMSO and EurArgo (Emso is a research infrastructure dealing with moored observatories and EurArgo is also a research infrastructure, the European manifestation of Argo. It has developed a heavy Carbon focus and will include innovations in sensors, platforms and interoperability, along with a training component, the usage of multiple ICOS platforms for testing and a demonstration cruise.

# Central Analytical Laboratories -Central Radiocarbon Laboratory (CAL-CRL)

## Highlights

- More than doubling of the number of ICOS stations sending flask samples to CRL for  $^{14}\text{CO}_2$  analysis.
- In-depth investigation of the applicability of CO and NO<sub>x</sub> as fossil fuel CO<sub>2</sub> surrogate tracers at the ICOS CRL pilot station and ICOS-KIT station.
- Over three decades of global atmospheric background <sup>14</sup>CO<sub>2</sub> legacy data have been re-evaluated, quality controlled and made freely available via the ICOS Carbon Portal.

The structure of the CRL Annual Report 2021 and the numbering of the deliverables follow the CRL Work Plan for 2021.

## Radiocarbon analysis of bi-weekly integrated CO<sub>2</sub> samples (Task 1)

In 2021, 16 atmospheric ICOS class 1 stations provided integrated CO<sub>2</sub> samples to the ICOS CRL. Additionally, we analysed integrated samples from the ICOS class 2 station Izana and the ICOS CRL pilot station. Samples from the non-ICOS station Mace Head have been analysed in addition. Mace Head and Izana are key stations for determining the marine <sup>14</sup>CO<sub>2</sub> background concentration. The marine background can be used alternatively to the continental background estimate derived from the <sup>14</sup>CO<sub>2</sub> measurements at Jungfraujoch station. In total, 323 European samples were analysed by low-level counting. In addition, we analysed 39 integrated <sup>14</sup>CO<sub>2</sub> samples from the polar stations Neumayer (Antarctica) and Alert (Arctic) as well as from Toronto and Egbert (the latter two paid by EC, Canada). The collaboration measurements for Environmental Canada were completed with these measurements, and no further analyses are planned.

All level-1 and level-2 results have been transferred to the CAL database in Jena and forwarded to the ATC. Therewith, Deliverables 1 and 2 were fulfilled.

Personnel task 1: 22.1 PM

#### Radiocarbon analysis of CO<sub>2</sub> from flask samples (Task 2)

In 2021, the long-awaited increase from 5 to 12 ICOS Class 1 stations sending in flask samples for  ${}^{14}CO_2$  analysis. However, the number of ICOS flask analyses remained approximately the same at 251 compared to 253 in the previous year. This can be explained by the fact that half of the ICOS stations started sending samples only towards the very end of the year 2021 and the fact that in 2020 more flask samples from the ICOS-KIT station were analysed due to a service contract between the DWD and the ICOS CRL.

As described in the CRL work plan for 2021, free flask analysis capacity has been used for various purposes as outlined in the work plan sections "Operation of the ICOS Pilot station" and "Projects and international collaboration". The larger part of the free capacity was devoted to the CRL pilot station to develop new sampling strategies and to test surrogate tracers for regional fossil fuel CO<sub>2</sub> estimation. In total, we analysed 155 flask samples collected at the ICOS CRL pilot station. Among other usages, these samples are used to test potential surrogate tracers for fossil fuel CO<sub>2</sub> (see sec.: Operation of the pilot station). We finalised the measurements for the VERIFY project by analysing another 49 campaign samples. The VERIFY project did cover the AMS analysis costs of those samples and provided human resources for the sample preparation. In total, we analysed 455 flask samples in 2021.

The quality control monitoring of the flask extraction- and graphitisation-line and the subsequent AMS measurements were ongoing in 2021. Based on oxalic acid 1 (SRM 4990 B) measurements, the international <sup>14</sup>C scale could, on average, be reproduced to  $0.26\% \pm 0.22\%$  for the period between July 2017 to the end of 2021. However, it must be noted that from July 2017 to the end of 2019, a negative deviation of  $-0.2\% \pm 0.3\%$  and from 2020 to the end of 2021, a positive deviation of  $0.9\% \pm 0.3\%$  to the nominal value is found, resulting in a change of  $1.1 \pm 0.4\%$  between pre and post 2020. The two internal whole air quality control gases show for pre and post 2020 an increase of  $0.67\% \pm 0.36\%$  and  $0.31\% \pm 0.67\%$  in their average values, respectively. So far, we have no indication of the cause of this shift. We will continue to work on identifying the causes and carefully monitor the potential drift in our laboratory. In contrast to the deterioration in the accuracy, the reproducibility of the internal whole air quality control gases has improved in 2021 and is below 2‰ for both gases. We also continued to analyse a subset of the integrated <sup>14</sup>CO<sub>2</sub> samples also by AMS for quality control purposes. Also, for this quality control parameter, we identify a pre and post 2020 difference of  $0.96\% \pm 0.46\%$  between the AMS and LLC measurements. This shift is comparable to the observed shift in the oxalic acid 1 (SRM 4990 B) AMS measurements.

Level-1 and Level-2 data have been transferred to the station PIs on request. No official flask dataset was released by the ATC and the CP yet. Thus, Deliverable 3 and 4 have been accomplished by manual data transmission.

Personnel task 2: 21.8 PM

#### Production of integrated CO<sub>2</sub> samplers (Task 3)

In 2021 no integrated  $CO_2$  samplers were built. Trainou and Schauinsland stations continue to use the existing integrated  $CO_2$  samplers, which they already had as part of their former role in the global Heidelberg <sup>14</sup>CO<sub>2</sub> sampling network. Thus Deliverable 5 is not applicable. The administrative challenges with the Italian administration could be resolved so that the integrated  $CO_2$  sampler for the Lampedusa station can now be shipped.

Personnel task 3: 0.0 PM

#### Interaction with station PIs (Task 4)

CRL scientists participated in both virtual atmospheric MSAs (Deliverable 6). The <sup>14</sup>CO<sub>2</sub> results from integrated sampling and the flask sampling had been presented to the participants. There is a regular email exchange between the CRL and the stations concerning the supply of sampling bottles, spare parts, and other issues. The regular transfer of samples between the stations and the CRL works smoothly.

In 2021 there was increased demand for CRL's support in selecting flask samples (Deliverable 7). Together with the station PIs, the relevance of individual flasks for the  ${}^{14}CO_2$  analysis was discussed, and criteria for  ${}^{14}CO_2$  sample selection have been developed.

Personnel task 4: 3.6 PM

## **Operation of the ICOS Pilot station, development of ffCO<sub>2</sub> detection strategies and data evaluation (Task 5)**

In 2021 the CRL operated the ICOS CRL pilot station, including:

- continuous in-situ measurements with ICOS-compliant CRDS and FTIR analysers
- continuous in-situ NO and NO<sub>2</sub> measurements
- semi-continuous in-situ <sup>222</sup>Rn measurements
- flask sampling using the ICOS flask sampler
- integrated CO<sub>2</sub> sampling for <sup>14</sup>CO<sub>2</sub> analysis

With the continuous operation and the transmission of the in-situ GHG data to the ATC, Deliverable 8 was fulfilled.

Personnel CRL pilot station operation: 6.6 PM

In developing  $ffCO_2$  monitoring strategies, the focus in 2021 was on investigating the potential of the  $ffCO_2$  surrogate tracers CO and  $NO_x$ .

As part of his dissertation, Fabian Maier investigated the relationship between CO and  $ffCO_2$  at the CRL pilot station from 2018 onwards. This also required a renewed in-depth study of the fundamental issues of the <sup>14</sup>CO<sub>2</sub>-based  $ffCO_2$  determination, such as contamination corrections due to nuclear <sup>14</sup>C emissions or the dependence of  $ffCO_2$  estimates on the choice of background signal. For the CRL pilot station, it can be shown that the CO-based  $ffCO_2$  estimates agree very well with the <sup>14</sup>CO<sub>2</sub>-based  $ffCO_2$  estimates but that the errors of the CO-based estimates are about a factor of three larger. Due to the large number of <sup>14</sup>CO<sub>2</sub> samples collected at the CRL in 2018-2020, these results can be supported with an

unprecedented wealth of data. Fabian Maier is currently working on a manuscript summarising these findings, which are also transferable to other ICOS stations.

A second publication, prepared by Cornelia Jäschke, addresses the potential of the simultaneous use of  $^{14}CO_2$ , CO and NO<sub>x</sub> for the sectoral attribution of ffCO<sub>2</sub> emissions. In this paper, the theoretical framework and limitations of this multi-proxy source attribution approach are elaborated and compared to actual measurements at the CRL pilot station and the ICOS-KIT station.

In cooperation with the MPI-BGC in Jena, ffCO<sub>2</sub> modelling was incorporated into the CarboScope TM3 inversion system. The inversions performed using ICOS and pre-ICOS <sup>14</sup>CO<sub>2</sub>-based ffCO<sub>2</sub> estimates show the system's functionality. Still, the coarse spatial resolution of the TM3 model (5° longitude and ca 4° latitude) does not allow for an adequate representation of the individual ICOS stations in the model. We expect that this deficit will improve significantly with the nesting of the STILT model in TM3, which will be worked on in 2022.

Personnel ffCO<sub>2</sub> strategies and data evaluation: 6.9 PM (+ 12 PM from DWD service contract)

#### Activities and plans reported to the DG, RI Committee and General Assembly (Task 6)

Annual and financial reports for 2020 (Deliverable 8), as well as the work- and the financial plan for 2022 (Deliverable 9), have been submitted to the HO in time. S. Hammer participated in the virtual 14th and 15th GA as well as in both virtual RI COM face-to-face meetings in 2021. With very few exceptions, S. Hammer has participated in the regular monthly teleconferences of the RI COM.

Personnel: 3.6 PM

#### **Other important activities**

The publication of the continuous  $O_2/N_2$  measurements conducted at the CRL pilot stations from 2019 to 2021 and thus Deliverable 10 was not achieved. This is because we first needed to establish the improved and standardised methodology for the <sup>14</sup>CO<sub>2</sub>-based ffCO<sub>2</sub> estimation and its uncertainties at the CRL station. This has now been achieved during Fabian Maier's dissertation, and the evaluation of the benefit of APO as a ffCO<sub>2</sub> tracer can be continued.

In 2021, CRL completed the re-evaluation and quality control of more than three decades of atmospheric <sup>14</sup>CO<sub>2</sub> legacy data. These pre-ICOS data from global background stations are now compatible with the current ICOS data and freely available via the Carbon Portal. This data release was linked to a publication by Levin et al. (2021) describing the evolution of global <sup>14</sup>CO<sub>2</sub> activity concentrations.

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## **Flask and Calibration Laboratory (CAL-FCL)**

#### Highlights

- Coverage of ICOS flask sample programme has doubled
- WMO CO<sub>2</sub> scale update of all FCL measurements concluded

## Trace gas analysis (CO<sub>2</sub>, CH<sub>4</sub>, CO, N<sub>2</sub>O, SF<sub>6</sub>, H<sub>2</sub>) of flask samples (Task 1)

The flask sampling network in ICOS made significant progress in 2021. The number of ICOS class 1 stations that have started their sampling programme has increased to 15. The quantity of samples that have been analysed at FCL has doubled to 3108 and has reached the envisaged GC analysis capacity (Deliverable 1). A further expansion of the amount of ICOS sample numbers is foreseen and still possible with a reduced internal need of test samples (e.g., for method development and the check of outgoing flask samplers). Discussions with the ATC have resulted in an agreement on flask sampling and flask data file formats for data reporting, the flagging scheme and data versioning. Implementation of these specifications has started at both central facilities. In the wake of the WMO CO2 scale revision all flask CO<sub>2</sub> measurement result have been reprocessed and transferred to the new X2019 mole fraction scale (Milestone 3). Problems with the defective detector for CO analysis were resolved in March 2021.

## Analysis of supplement parameters (CO $_2$ stable isotopes and O $_2/N_2$ ratios) (Task 2)

In previous years the focus of this task had been to enable the ICOS Atmosphere network performing air sampling by developing, constructing and providing the sampling devices and containers required for the purpose. This now has largely been accomplished with one more sampler having been delivered to an ICOS station (SAC, France) in 2021. As mentioned in Task 1 the flask sampling programme has grown significantly in 2021. All station air flask samples mentioned in Task 1 have been analysed for  $CO_2$  stable isotopes and  $O_2/N_2$  ratios (Deliverable 2).

## Production of real air high pressure standard gases (CO<sub>2</sub>, CH<sub>4</sub>, CO) (Task 3)

Standard gas cylinders for ICOS stations were prepared as requested. A total of 124 reference gases were provided to 34 atmospheric stations or ICOS Atmosphere Central Facilities (Deliverable 3).

Since 2020 FCL is also in charge of providing reference gases for ICOS ocean SOOP stations. For this, the automated data processing routine for analysing  $CO_2$  mole fractions beyond the range of the WMO calibration scale has been established. A total of 40 standards has been produced, calibrated and delivered to the OTC and ICOS ocean PIs. Another 18 cylinders were prepared to be available as exchange sets when needed.

#### Calibration and re-calibration of standard gases (Task 4)

All standard gases produced in task 3 have been calibrated plus another 52 standard gases that were returned to FCL for re-calibration (Deliverable 4).

In February 2021, the WMO Central Calibration Laboratory (CCL) has released the  $CO_2$  X2019 scale revision with the request to all contributing measurement networks to update the reported  $CO_2$  data. This entailed a re-assignment of the ICOS primary reference gases, re-evaluation of the stability of the FCL laboratory standards and the reprocessing of all FCL  $CO_2$  calibration measurements. The data transfer of the revised calibration results to the ATC was completed in October 2021 (Milestone 3).

Six Replacement Sets are available for periods when stations return their standard gases for recalibration. In 2021 this has been used by the stations SE-HTM, SE-NOR, SE-SVB, FR-PUY, IT-PRS and FI-SMR (Deliverable 5).

## Organisation of and participation in international QC activities (Task 5)

The international QC activities have been retarded by the pandemic situation at partner laboratories. The "MENI" (**M**PI-**E**MPA-**N**OAA-**I**COS) round robin cylinders sent to Boulder in 2020 have not yet returned. While the delayed WMO Round Robin 7 has been started in 2021 the samples have not yet arrived at the FCL (Milestone 4). Three additional sets of each six "Sausage"- flask samples have been prepared and distributed to the participating seven participating laboratories (Deliverable 6). All CO2 intercomparison results have also been revised following the scale revision. This update has led to an excellent agreement with the NOAA laboratory with an average offset of  $0.00 \pm 0.02$  ppm.

The QC report was updated and made available on the FCL webpage considering the results from all internal and external QC activities conducted in 2021 (Deliverable 7).

## Activities and plan reported to the DG, RI Com and General Assembly (Task 6)

The general report (Deliverable 8) including the financial and activity report 2020 has been submitted to the HO in Feb 2021, the budget and work plan for 2022 were provided in September 2021. Additional time was devoted to contribute to the preparation of the ICOS management plan. A. Jordan was participating at the virtual General Assemblies in May and November 2021 providing updates on FCL activities. He also joined both virtual RI COM face-to-face meetings in 2021 and the regular monthly RI COM web conferences.

#### **Interaction with station PIs (Task 7)**

The FCL scientists participated at the virtual ICOS Atmosphere MSA meetings in February and December 2021. The reports on FCL activities were put up for discussion. FCL members were also contributing to the Quality Management working group meeting in March 2021. Daily communication of specific topics (e.g., reference gases, flask samples, flask sampler) between individual station PIs, other central facilities and FCL is facilitated by dedicated mailing lists and named contact persons (Deliverable 9).

The intended flask sampler technical user workshop could not be organized due to COVID restrictions in 2021 (Milestone 2). Field support for flask samplers was provided by technical advice, flask sampler software updates and if necessary field visits, which has been done to 4 ICOS stations.

#### **Other important activities**

A series of comparison measurements between the ICOS flask sampler developed by us and in situ measurements have been performed with the goals:

- to improve the sampling process itself by identifying sampler software errors
- to improve the comparability between sampled flasks and in-situ measurements

- test of event-controlled sampling schemes (i.e., wind direction or in-situ concentration dependent)

Furthermore, the flask sampler software was extended towards allowing sampling from different inlet levels and communication with the devices controlling the in-situ instruments like the newly developed ICOS ATC scheduler.

Automatization of flask related lab procedures to optimize effectiveness and minimize operator error rates has been advanced by a new software engineer. This includes the flask leak test instrument but also the automatized collection of data related to the physical status of each flask to identify flask problems in advance and assure the ICOS flasks quality over time.

Within the ICOS Cities Project a hard- and software extension of the flask sampler for Relaxed Eddy Accumulation (REA) is developed in collaboration with Sam Hammer and Andreas Christen. During a period of time up- and downwind air is collected in two different flasks using a setup consisting of fast switching inlet valves, inlet pumps and buffer volumes. First proof of principle experiments have been performed in 2021. The completely automated system will be deployed the first time in Zürich mid-2022.

The BIPM has asked the ICOS FCL to participate in the CCQM - GAWG's (Consultative Committee for Amount of Substance - Gas Analysis Working Group's) Task Group on GHG Scale Comparisons. FCL is contributing jointly with colleagues from NOAA and other laboratories with its experience in protocols for determining and maintaining scale relationships and intercomparisons.

## **Atmosphere MSA**

- Two MSA atmosphere virtual meetings were held in 2021 on February 1-2 and December 1-2. More than 80 participants attended to both the meetings. Activity updates were provided by Head Office, Atmospheric Thematic Centre, Carbon Portal and Calibration Laboratories. Sessions were mainly about technological advances and related discussions (e.g. updates in the ICOS flask autosampler, a new sequencer system for tall-tower, software for flagging Rn data, optimization of the use of flask sampling for QC, optimization of flask sampling at remote sites for <sup>14</sup>C...). During these meetings, the implementation to the ICOS data of the new WMO calibration scale for CO<sub>2</sub> in air (WMO CO2 X2019) was discussed. Scientific presentations about different topics (e.g. CH4 in the Artic, use of combined tracers for assessing fossil fuel CO2 emissions ...) were provided by the MSA members. As always, specific sessions were dedicated to the joint data review of the ICOS atmosphere data recorded since the previous MSA meeting.
- A special MSA virtual meeting about raw data policy was organized on September 16, 2021.
- Very good participation of MSA members to the online Carbon Portal webinars about using Carbon Portal and Juypter Notebooks (https://www.icos-cp.eu/cp-webinar).
- Three working groups have been activated for the optimization of spike detection algorithms, for the management of data quality of atmospheric observations and for preparation of a European GHG dataset.
- An internal survey was launched within the MSA to collect ideas about how to strength/optimise the internal communication within the MSA and with ECO and OCE MSAs.

- Paolo Cristofanelli from Italy and Dagmar Kubistin from Germany were elected in December 2020 as MSA atmosphere chair and vice chair, respectively.
- Release of level-22 data of 26 atmospheric stations (67 vertical levels) https://doi.org/10.18160/H522-A9S0.
- 7 new class-2 atmospheric sites got the ICOS label (Jülich Observatory (JUE) Germany; Westerland (WES) – Germany; Weybourne (WAO) – UK; Birkenes Observatory (BIR) - Norway, Plateau Rosa (PRS) – Italy; Puijo (PUI) - Finland, Zugspitze (ZSF) – Germany): up to now 33 atmospheric sites have been labelled.
- ICOS atmosphere data are continuously used by the Copernicus Atmosphere Monitoring Service for evaluating its global forecasting system (https://global-evaluation.atmosphere.copernicus.eu/co2/ghg/insitu-icos)
- Documentation of operational procedures is continuously discussed and elaborated at the MSA meetings.
- A scientific paper describing the "Evaluation and optimization of ICOS atmosphere station data as part of the labeling process" (Yver-Kwok et al., 2021) was published on Atmos. Meas. Tech, <a href="https://doi.org/10.5194/amt-14-89-2021">https://doi.org/10.5194/amt-14-89-2021</a>
- MSA members participated to combined GAWTec / Young Earth System Scientists community webinar series on GHG in 2020/2021 presenting ICOS activities (https://www.yess-community.org/gawtec-webinar-series-2020/)

### **Ecosystem MSA**

- Similar to the Drought 2018 initiative, a new integrated data initiative on the Warm Winter 2020 was launched, with strong contribution from the MSA members in terms of both data production and scientific activity. The data release includes 73 stations, extending in time and number the Drought 2018 data release, and all data come from the ecosystem domain. The large majority of working groups (WGs) proposed within the initiative is inherent to the activities of ECO-MSA members
- Ecosystem MSA Meeting in February (3&5 Feb, 64 participants) : Janne Rinne, ECO MSA chair announced he will be leaving ICOS. Discord was elected as an extra communication channel for eco MSA. Discussions focussed on the processing of legacy data, visualizations of NRT data, and the authors list for data product citations.
- Ecosystem MSA Meeting in May (5-6 May, 50 participants): Discussions focused on several ICOS instructions and ways to improve them with request to ETC of clarifications and simplifications; scientific results have been presented from three WGs in the framework of Warm Winter initiatives. Different data products, i.e. near-real-time, Level2 and interim-Level2 ICOS were presented by and discussed with the ETC, as well as the implementation priorities following RINGO results.
- Ecosystem MSA Meeting in October (19&22 Oct, 59 participants): New chairs were elected: Marlyn Roland and Nicola Arriga. HO and CP<sup>¬</sup>gave a status update and planned acitivities. Plans to activate WGs, one on proposals preparation and one on the update os stations instrumental set-up. Discussion on PPFD\_BC (below canopy Photosynthetic Photon Flux Density) experimental testing by some stations, under the supervision of ETC, to propose an alternative to DHP (Digital Hemispherical Pictures) for green area index (GAI) measurements in forest sites. Updates from Warm Winter 2020 WG leaders, with one of them submitting an abstract to the 2022 EGU Assembly

- Two new MSA chairs have been elected to replace the previous two, Janne Rinne and Lukas Siebicke who moved to non-ICOS institutions. Marilyn Roland (University of Antwerp, Wilrijk, Belgium) and Nicola Arriga (European Commission Joint Research Centre, Ispra, Italy)
- Questionnaire to investigate status and perspective of the MSA members has been prepared by the MSA chairs and sent to the whole MSA in December. In particular focus has been given to the ICOS and non-ICOS measurements available at the stations, on the outlook for Instrumental improvement, on the eventual issues with ICOS Instructions. In total 47 stations had timely and exhaustively replied, providing useful description and improvement suggestions.
- Newly labelled stations: during 2021 a total of 15 ecosystem stations have received the ICOS label for full compliance with the standards. Three of them are class 1 stations (Castelporziano IT-CP2; Auchencorth Moss UK-Amo and Sorø DK-Sor), three class 2 (Grignon FR-Gri; Puechabon FR-Pue and Renon IT-Ren) while the remaining nine are associated stations (Bosco Fontana IT-BFt; Disko GL-Dsk; Gludsted Plantage DK-Gds; Kenttärova FI-Ken; Rollesbroich DE-RuR; Třeboň CZ-Wet; Nuuk Fen GL-NuF; Skjern DK-Skj and Touluse FR-Tou). With these new entries the total number of ICOS labelled ecosystem stations raised up to fifty units.
- New ICOS data release: three important data releases occurred in ICOS for the ecosystem domain. The Level2 data collection for the whole 2020, i.e. the first year with a significant number of stations, has been released in spring 2021. Following ETC proposal at the MSA, several stations agreed to have a so-called interim-Level2 data release to cover the long gap between two successive annual Level2 releases. The proposed period for this release is since January until end of October and in November the data collection has been released. WarmWinter2020 (interim and final) have been produced by the European Fluxes Database Cluster staff in close collaboration with the ICOS-CP who finally published this release, based on the data spontaneously provided by the PI for 73 stations (see above). This dataset covers also the pre-ICOS period.

## **Ocean MSA**

- The 1<sup>st</sup> ICOS OTC pCO2 inter-comparison took place in VLIZ, Belgium. OTC (Tobias Steinhoff) organized the activity and MSA had a significant representation with PIs and the MSA chair (Thanos Gkritzalis) being active in the event. The activity attracted interest from around the world.
- 6 monthly MSA meetings to enhanced interaction between OTC, HO and MSA chairs. 16<sup>th</sup> Feb 2021 36 participants, 11<sup>th</sup> October 25 participants.
- JPI meeting and workshop attended by MSA chairs and some station PIs to raise the ICOS profile and look into national funding opportunities in the future. ICOS leads on North Sea and Atlantic.
- February and September 2021: Twice a year station 'Ring Arounds' in the Ocean community continued (will be annual from 2022). This provided information to OTC and HO on the situation of the stations. This survey continued to highlight issues with funding and in the impacts of covid.
- Stations are benefiting from the existing support mechanisms that OTC and HO are providing, such as the training (and pCO2 inter-comparison), QuinCe, standardized calibration gases, calibration of sensors, use of Jupyter notebooks, etc.

- Two working groups were initiated: Dissolved oxygen measurements (November 2021) and Fixed Ocean Stations (1<sup>st</sup> meeting 16th sept).
- Establishment of additional monthly, online MSA chats from November 2021 onwards. These
  chats are an informal place for the MSA to meet and share and discuss current issues. In turn
  they hear what is happening in the OTC weekly meetings and in the HO RICOM meetings (both
  of which are attended by the MSA chairs). This will assist in communicating and sharing
  information on issues such as station support and EU funding initiatives. These meetings are
  intended to improve the communication withing the MSA and towards MSA-Chairs.
- MSA chair on committee for ICOS science conference.

## Belgium

#### Highlights

Funding obtained:

- Under the framework of the ESFRI-FED call, the ICOS-BE project titled "Strengthening the Belgian contribution to ICOS" has been funded for the period 12/2021 03/2026. The project partners are the Royal Belgian Institute for Space Aeronomy (BIRA-IASB) as the project lead, the Royal Belgian Institute of Natural Sciences (RBINS), Ghent University (UGent) and University of Antwerp (UAntwerp). The funding includes the continuation of ICOS and related TCCON observations at Reunion Island, further improvement of the oceanic ICOS-type measurements with the AUMS onboard the new research vessel RV Belgica with the goal to achieve the ICOS labelling, initiation of remotely sensed COCCON-type observations at the ecosystem site, with a first testing in Belgium and later deployment at the Congoflux tower site in the Democratic Republic of the Congo in collaboration with UGhent and UAntwerp.
- Project renewal: phase 2 of the ICOS-WB project started in July 2021 with a 5-years funding by the Walloon Region.

#### Changes in station network

 Simon Stevin: The BE-SOOP-Simon Stevin received the ICOS Class 1 label in the May 2021 General Assembly. The NRT data from the station are available in the Carbon Portal (PID: 11676/R\_Fj5ri4ubanvj4ez3nX8sJ2) and level 2 will be available in the relevant releases from the ICOS Carbon Portal (www.icos-cp.eu).

#### **Provided training**

- Summer schools, workshops organized by National network
  - Instrument intercomparison VLIZ: VLIZ hosted an international pCO<sub>2</sub> sensors/systems inter-comparison activity from 28 June until 11 July 2021 (https://otc.icos-cp.eu/node/144). This has attracted interest from renounced international groups working on Marine Inorganic Carbon Research. The event was funded by ICOS OTC and highlighted the importance that VLIZ and the VLIZ ICOS infrastructure can have on the international research arena for Marine Inorganic Carbon Chemistry.
- PhD and master students graduated (using ICOS data or otherwise related to ICOS NN).

- o PhD
  - Miro De Mol: a joint PhD between the UAntwerp and Ghent University on the improvement of Aboveground biomass in forest using Terrestrial Lidar. This PhD thesis was supervised by Dr. B. Gielen (UAntwerp, ETC) and Prof. H. Verbeeck (UGent). This thesis made use of the expertise present in the ICOS ETC and performed field campaigns at several ICOS stations in Europe.
- MSc thesis:
  - Freke van Damme and Hanna Mertens: Both students completed their master thesis successfully in 2021 on the effect of forest management on carbon sequestration and performing field work at the ICOS station in Brasschaat. Both were supervised by Dr B. Gielen and Dr. M. Roland.
  - Matthieu Delespesse : Measure of N<sub>2</sub>O fluxes of an agricultural soil : emission dynamics and impact of soil preparation on the seasonal budget.
  - Clara Cravatte: Study of the partitioning of the water vapour flux exchanged by ecosystems between transpiration and evaporation.
  - Florian Vanden Brande: Estimation of Solanum Tuberosum L. carbon assimilation by the Farquhar model : Evaluation of performance and attempts of improvement for water stress episodes.
- Post-doc:
  - Wafa Chebbi: Evapotranspiration and water balance of a mixed forest in Belgium and its response to spring/summer temperature and drought with both available data (long time series 1996 to 2020) and modelling

#### **Co-operation with other RIs**

- VLIZ stations BE-FOS-Thornton Buoy and BE-SOOP-Simon Stevin are contributing both on ICOS and LifeWatch.
- ACTRIS RI (road map ESFRI 2016): "Aerosols, clouds and trace gazes European research Infrastructure" with BIRA, KMI, IsseP, Ulg :
  - Vielsalm station involved. Implementation step (=>2024). Foreseen installation on the site of a PTR-(TOF)-MS and a MAX-DOAS (Airyx SkySpec system).
  - At the Réunion atmospheric station BIRA-IASB already operates a ground-based remote sensing UVVIS MAX-DOAS and FTIR instrument that measure the column abundances of various short-lived climate pollutants above the site. The site will be collocated with the joint French-Belgian OPAR National Facility for reactive trace gases remote sensing within the ACTRIS Research infrastructure.
- BIRA-IASB is member of ATMO-ACCES Science Steering Committee (SSC) and Strategic Trans-National and Virtual Access Board (STVB).

#### **Use of ICOS stations**

BERTRAC – BELSPO FEDtWIN: Post-doc for reactive gases (5 years minimum) accepted in 2021.
 "Investigation of bidirectional surface/atmosphere exchange of reactive trace compounds in terrestrial ecosystems through measurements and modelling" with Crist Amelynck (BIRA-IASB)

and Bernard Heinesch (ULiege). Includes activities on Vielsalm station and possibly on other sites.

- SoilTemp (BECROP): project aims to map soil health in agricultural systems using DNA analysis of soil microbial communities. Soil samples provided during 2021 grozing season. Scientific paper Lambrecth et al. submitted in August 2021, accepted.
- CarboN2O: thesis (starting in 2022) in cotutelle INRAe-Laon and ULiege-GxABT within the transborder UMR BioEcoAgro, and which will analyze the impacts of residues management (for increasing soil C) on N2O emissions through field data and process-based analysis. Lonzée station involved.
- ICLSDesMod : Innovative integrated crop-livestock systems design with the aim of optimising farming systems resilience and relocating food production. Historical data from ICOS Lonzée and ULg-GxABT. Soil-Residue trial are used to parameterize a soil-crop model on the GHG emission response.
- ETP formalization : Develop and evaluate a modified version of a Priestley-Taylor type ETP model to improve SALUS soil-crop model. Historical data from ICOS BE-Lon will be used to parameterize a the coefficient of the modified Priestley-Taylor ETP model, and account for the crop type.
- NEC (Walloon Agency for air and climate): evaluate the impact of the atmospheric pollution on the ecosystems and habitats.
- Forest Flow (BELSPO): Estimation of dissolved organic compounds flows at the scale of the plot and the watershed (UA, KUL, UCL, IRM) : Vielsalm station involved.
- PQRVF (formerly ACRVF, (DGO3, SPW)) : Assessment of water stress in the soils of the walloon forest: best estimate of extractable water : Vielsalm station involved.

## **Czech Republic**

#### **Changes in station network**

• Trebon wetland station labelled on 25 May 2021

#### **Provided training**

- Summer schools, workshops organized by National network
  - Annually is given in average 40 lectures (during 2020 were instead of physical a few online) for the general public (among others the Week of Science and Technology organised annually by CAS). The very important part of the lecturing and training activity are lectures to specific groups such as companies' managers (e.g. energy company ČEZ a. s.) or policy-makers (e.g. government, regional authorities, municipalities).
  - Excursions for students in Bc. and MSc. study programmes, experts, and/or organisations involved in research and development are regularly organised. There are approximately 20 CzeCOS excursions per year, however due to COVID-19 during the year 2021 only a few were organised. Moreover, excursions for the general public are organised during so-called "LRI open days" including excursions within Week of Science

and Technology etc. organised by CAS, CzechGlobe itself, and/or local authorities for requests.

- PhD and master students graduated (using ICOS data or otherwise related to ICOS NN).
  - MSc. Mensah Caleb– Dissertation Thesis Analysis of eddy covariance data measured in terrestrial ecosystem, Mendel University in Brno, Faculty of AgriScience, 2021
  - Mgr. Ondřej Nezval Dissertation Thesis Vyhodnocení fenologických pozorování na vybraných hospodářských dřevinách (An assessment of phenological observations of the most important commercial species in the Czech Republic), Mendel University in Brno, Faculty of Forestry and Wood Technology, 2021
  - Ing. Michal Bellan Dissertation Thesis Kvantifikace tvorby nadzemní biomasy smrkového porostu (Quantification of above-ground biomass formation of spruce stand), Mendel University in Brno, Faculty of Forestry and Wood Technology, 2021
  - Ing. Jana Rosíková Dissertation Thesis Vliv vápnění na půdní respiraci a vybrané biochemické vlastnosti povrchových horizontů ve smrkové monokultuře ekosystémové stanice Rájec-Němčice (Influence of liming on soil respiration and selected biochemical properties of spruce monoculture topsoil horizons in Rájec-Němčice Ecosystem Study Site), Mendel University in Brno, Faculty of Forestry and Wood Technology, 2021

#### **Co-operation with other RIs**

ICOS CZ host institute research infrastructure is also part of: ESFRI ACTRIS, DANUBIUS-RI, AnaEE ERIC and eLTER RI and it is founding member of EUFAR AISBL and these interlinks are used for interdisciplinary research.

Collocation stations:

- Křešín u Pacova atmospheric station (ICOS/ACTRIS).
- Bílý Kříž ecosystem station (ICOS/AnaEE/eLTER)
- Trebon wetland station (ICOS/eLTER)
- Lanžhot ecosystem station (ICOS/DANUBIUS-RI)

## Denmark

#### Highlights

Several station in the Danish/Greenlandic ICOS network were labelled in 2021, which also bring the establishment of the Danish/Greenlandic ICOS close to an end. During 2021 the ecosystem stations in Kobbefjord(assoc), Disko (assoc) both in Greenland were labelled as well as the associated stations in Gludsted and Skjern enge and the class 1 station in Sorø forest were labelled. Also the only atmospheric station, Station Nord, in Danish/Greenlandic ICOS was labelled in 2021 though with some conditions related to the harsh environment of the site.

A dedicated work has been initiated in Denmark to increase the awareness of ICOS and ICOS data as well as the promotion of the use of the facilities at the ecosystem sites.

We were in Copenhagen fortunate to be able to host the ICOS General Assemble in November

#### **Changes in station network**

 Stations completing labelling in GA meetings of 2021 are DK-SKJ, DK-GDS, DK-SOR, GR –SNO, GL- DSK, GL-NUF

#### **Provided training**

- Co-organizing Nordic ICOS symposium
- Johan Scheller PhD, Aarhus University on data from Zackenberg.

#### **Co-operation with other RIs**

Collaboration between ICOS and ACTRIS at Station Nord, Collaboration at all Greenlandic ecosystem sites between ICOS and Greenland Ecosystem monitoring program (<u>https://g-e-m.dk/</u>)

## Finland

#### **Changes in station network**

Stations completing labelling in GA meetings 2021

- $\circ~$  Puijo ATM station, class 2
- o Kenttärova ECO associate station

#### **Provided training**

- Summer schools, workshops organized by National network  $\circ$  ICOS summer

school organized in Hyytiälä December 2021

- PhD and master students graduated (using ICOS data or otherwise related to ICOS NN).
  - Arola, A. 2021: On the use of Brunt-Vaisala frequency as a proxy for surface water pCO2 in a small boreal lake. MSc thesis. University of Helsinki
  - Strömberg, J. 2021: The impact of thermal turbulence on flow conditions in a real street canyon using large-eddy simulations. MSc thesis, University of Helsinki
  - Frühauf, Y., 2021: Photosynthetic potential and chlorophyll fluorescence in different canopy heights in three tree species grown in different urban conditions. MSc thesis, University of Helsinki o Soininen, J., 2021: Mikrometeorologisten suureiden vaihtelu

kolmella erilaisella viheralueella Helsingissä. BSc thesis, University of Helsinki

- Laasonen, A., 2021: Biogenic carbon monoxide fluxes in four terrestrial ecosystems. MSc thesis, University of Helsinki
- Haverinen, S. 2021: Pohjoisboreaalisen järven ja sen valuma-alueen puron metaanivuon alueellinen ja ajallinen vaihtelu. MSc thesis, Univ. Helsinki
- Kuuri-Riutta, O. 2021: Recent changes in the vegetation of a subarctic fen implications for carbon dynamics. MSc thesis, Univ. Helsinki.

#### **Co-operation with other RIs**

- Joint use of ICOS stations with other RIs eLTER, ACTRIS and AnaEE at stations Hyytiälä / SMEAR II, Pallas stations (Sammaltunturi, Lompolojänkkä, Kenttärova) and Värriö. Join use of ICOS stations with eLTER at stations Siikaneva / SMEAR II and Kuivajärvi / SMEAR II and with ACTRIS at Puijo / SMEAR IV and Utö stations
- ICOS-type stations with ACTRIS-type measurements set up at Naarasneva (former peat extraction area) and Haltiala agricultural field. Not officially ICOS stations yet, but will be in the future

## France

#### Highlights

The H2020 PAUL (Pilot Applications in Urban Landscapes) project started with a kick-off meeting in Paris in December 2021. There are three major pilot cities in PAUL: Munich, Paris and Zurich. ICOS France started organizing and securing the Paris network allready in the third trimester of 2021. In particular nine high precision insitu measurement sites were identified together with 10 sites for mid-cost CO2 sensor deployment. Also, the first design of an integrated platform for mid cost sensors was produced. On the side of eddy flux measurements, 4 sites were identified with a tall tower complemented by three smaller one in the footprint of the tall eddy tower.

#### **Changes in station network**

- Three additional Ecosystem stations completed the labelling process and were acknowledged by the ICOS-RI GA in 2021: the cropland site Grignon (FR-Gri, class 2, PI: P. Buysse), the forest site Puéchabon (FR-Pue, class 2, PI: JM Limousin), and the Toulouse grassland (FR-Tou, associated, PI: JC Calvet)..
- The French ecosystem network is expected to be labelled in 2022, with FR-Hes, FR-Lus, FR-Lq and FR-Fbn remaining stations to be proposed for labelling in May or November GA.
- Jérémie Depuydt has been recruited as site manager of the ecosystem station FR-GRI and Pauline Buysse named PI of that site.

#### **Provided training**

In 2021 four PH D dissertation thesis and 6 Master thesis in relationship with the French ICOS network were presented. Ph D. thesis are listed at the end of this document. The ICOS France community has organised a series of service and facilities allowing mutual and self-training (forums, webinars) managed by engineers, technicians and scientists.

The network organised 3 sessions of distant (due to COVID restriction) training for the site technical staff. Each meeting gathered about 40 peoples. The themes of the meeting were "how to fill BADM?", "tips for maintenance of EC system", "data exchange between site and the ETC". A French speaking web forum has also been setup to foster exchanges and keep track of the collective knowledge.

With the Covid-19 constrain, ATC has organized a 3 day "online" training. The attendees of this training were PIs/Staff from Germany, Italy, UK and Spain.

Impacts of the 2019 heat waves on the functioning of French ecosystems has been studied and presented to the French ICOS conference by a master student co-supervised by the members of the ICOS ecosystem network and financed by national CLAND project (Coimbra et al. 2021).

- The following Ph D thesis were successfully presented in 2021:
  - Chandra, V. Nitrous oxide and ammonia emissions from crop residue decomposition in soils, (2021). 20-09-2021 Sorbone Université.
  - Pique, G. Assimilating high-resolution satellite data for modeling spatially the yield, the C budget and the water consumption of croplands (2021). Université Toulouse Paul Sabatier
  - Dare-Idowu, O. Climate and management impacts on evapotranspiration and energy budget in irrigated fields: a multi-site experimental and modelling approach (2021). Université Toulouse Paul Sabatier
  - Pageot, Y. Remote sensing of water use and deficit in summer crops using Sentinel 1 and Sentinel 2 data (2021). Université Toulouse Paul Sabatier
- Msc thesis successfully presented in 2021:
  - Coimbra Herig, Pedro, 2021. Impact of heat wave episodes in summer 2019 on the carbon flux of the French ICOS sites inferred through modelling from ICOS Ecosystem stations in France.
  - Garnier, S. 2021. Canopy rhythm: analysing intra-population variability of budburst and leaf shedding in deciduous temperate forests. Université Paris-Saclay
  - Tredoulat, A. 2021. Spatial variability of soil and sub-soil assess from hydro-geophysical methods in the temperate forest ICOS site of Barbeau. Université Paris-Saclay

#### **Co-operation with other RIs**

- Obs4clim. The project Obs4Clim has been financed by French national research funding agency. This project will bring new instrumentations to the RI ICOS, ACTRIS and IAGOS in French sites, including ammonia and other GHG monitoring.
- INRAE has financed a spare sensors kit for the ecosystem network that will complement the ones from the CNRS and allow smoother operation during sensor calibration

#### **ICOS France Network meeting**

A major ICOS France meeting took place in Reims, Champagne-Ardenne region, October 12 to 14. In addition to a poster session, some 25 oral presentations were contributed with four invited keynote speakers: Valerie Mason-Delmotte, Frederic Chevellier, Richard Sanders, Mark Sutton. The last day was dedicated to meteo balloon, aircore demo launch together with the inauguration of a tower to deploy further GHG measurements.

#### **ICOS France Communication events**

- Participation to the Climate forum in Epernayin October with the loan of our set of ICOSscape exhibition panel.
- Participation in the science festival in October at OVSQ.
- Interactive project "The large scale" (evolution of CO2 concentrations over time via interactive video projection) in collaboration with the Orléans Museum for Biodiversity and the Environment.

### Germany

#### Highlights

The German ICOS network held its first physical meeting since the outbreak of the corona pandemic bringing together scientists from all three domains, technical staff, stakeholders and guests in September 2021. It was hosted by colleagues from Technical University of Dresden and included an excursion to the ICOS Tharandt Ecosystem Class-1 station.

Particular focus was given to studies from forest ecosystems investigating carbon and water fluxes for example after clear cuts and stressing the importance of long-term measurements for the derivation of sustainable management options. The meeting also presented a number of methodological studies addressing the relevance of linking ICOS data streams to products from the remote sensing and modelling community. Furthermore, new results were introduced from various research activities on greenhouse gas exchange in the Baltic Sea and from instrument inter-comparisons in the Ocean domain.

A specifically designed experiment was conducted at the ICOS Ecosystem Class-1 station "Hohes Holz" (DE-HoH). Twenty below-canopy sensors measuring photosynthetically active radiation (PAR) were installed for continuous determination of leaf area index (LAI). Data from this pilot project were evaluated by ETC with the aim to design a new instruction document for alternative LAI measurements.

ICOS Germany welcomes its first urban measurement station in the national network. The eddycovariance site is located on the street of Rothenburgstrasse in Berlin. Germany plays an important part in the EU project ICOS Cities, where Munich is one of the project's three pilot cities and Heidelberg belongs to the project's city network. The project is developing a concept for the holistic assessment of urban greenhouse gas emissions.

Scientists from ICOS Germany are participating in the "Warm Winter 2019/2020 Study" and the "Crop synthesis". While the Warm Winter study explicitly integrates alterations in greenhouse gas concentrations and fluxes from all three domains analysing the seasonal anomaly in 2019/2020 followed by the COVID-19 lockdown, the cropland study examines how the current management of European arable sites combined with the prevailing meteorological conditions affect  $CO_2$  fluxes and carbon stocks in arable soils.

#### **Changes in station network**

- Stations completing labelling in GA meetings of 2021
  - Class 2 Atmosphere Station Jülich Observatory (JUE)

- Responsible institution: Deutscher Wetterdienst, Hohenpeißenberg Meteorological Observatory; Station PI: Dagmar Kubistin.
- o Class 2 Atmosphere Station Westerland (WES)
  - Responsible institution: German Environment Agency Umweltbundesamt (UBA); Station PI: Cedric Couret.
- Class 2 Atmosphere Station Zugspitze (ZSF)
  - Responsible institution: German Environment Agency Umweltbundesamt (UBA); Station PI: Cedric Couret.
- Associated Ecosystem Station Rollesbroich (DE-RuR)
  - Responsible institution: Forschungszentrum Jülich (FZJ); Station PI: Marius Schmidt.
- New stations, stations changing e.g., Class1 to Associated, stations removed from network
  - o Berlin, associated ecosystem station, urban land use

#### **Provided training**

- Summer schools, workshops organized by National network
  - Lecture for GAWTec / Young Earth System Scientists community webinar series on GHG in 2020/2021 presenting ICOS activities (<u>https://www.yess-community.org/gawtec-webinar-series-2020/</u>) by DWD
  - Eddy Covariance Winter School for African students, technicians and postdocs, 24.-26.11.21, presenting ICOS methodologies (<u>https://www.emsafrica.org/courses/past-course-eddy-covariance-flux-measurements-intensive-course/</u>), hosted and organized by Thünen Institute
- PhD and master students graduated (using ICOS data or otherwise related to ICOS NN).
  - V. Kuch, 2021. Estimation of peatland evapotranspiration by means of remote sensing, Department of Geography, Ludwig-Maximilians-University Munich., Master thesis
  - Peter Miersch: "Partial Information Decomposition to Detect Drivers of Drought Impact on Gross Primary Production of Forests", University of Leipzig
  - Rifat Akon: BSc thesis on water use efficiency of crops at Gebesee site, TU Braunschweig, supervised at Thünen Institute
  - $\circ$  Kanisios Mukwashi: PhD thesis on CO $_2$  fluxes at South African tower sites, University of Bayreuth, supervised at Thünen Institute

#### **Co-operation with other RIs**

- SOCAT, SOCONET
- Using data from DE-SOOP-Atlantic Sail to validate biogeochemical measurements on BGC-Argo floats (Euro-ARGO)
- University of Heidelberg: Radon instrumentation at KIT station (DWD)
- University of Heidelberg: Source apportionment with NO<sub>x</sub> as anthropogenic tracer at KIT station (DWD)

- ICP Forests Level II, TERENO, MOSES, eLTER, GBOV, Aeronet, Biodiversity Exploratories, FLUXNET
- Cooperation with SAEON (South African Ecological Observation Network), student exchange, joint papers, concept for tower operation
- Ongoing cooperation between TU Dresden and Landesforst Brandenburg regarding ICOS ecosystem site Kienhorst (pine)

## Italy

#### **Changes in station network**

• Stations completing labelling in GA meetings of 2021

#### Stations having received the ICOS labelling in May 25, 2021

Class 1 Ecosystem Station of Castelporziano (IT-Cp2); *Responsible Institution*: CREA – Council for Agricultural Research and Economics; *Station PI*: Silvano Fares

Class 2 Atmosphere Station of Plateau Rosa (IT-PRS); *Responsible Institution*: Research on Energy Systems – RSE S.p.A; *Station Pl*: Francesco Apadula

Associated Ecosystem Station of Bosco Fontana (IT-Bft); *Responsible Institution*: Catholic University of the Sacred Heart of Brescia; *Station PI*: Giacomo Gerosa

Stations having received the ICOS labelling in November 17, 2021

• Class 2 Ecosystem Station of Renon (IT-Ren); *Responsible Institution*: Forest Services of the Autonomous Province of Bolzano; *Station PI*: Leonardo Montagnani

#### **Provided training**

The training activities of the Italian network during 2021 were strongly penalized by the pandemic situation due to Covid-19, which prevented the possibility to directly involve students in the field activities. Anyway, the following webinar events and lessons involving students to promote the ICOS activities have been provided:

- Lectures (4 hours) about ICOS and use of ICOS data at the PhD IN EARTHQUAKE AND ENVIRONMENTAL HAZARDS (EEH) by Paolo Cristofanelli at G. d'Annunzio School of Advanced Studies, in the Department of Psychological, Health and Territorial Sciences (DiSPuTer);
- Webinar lesson "CO<sub>2</sub> absorption by the ocean and the acidification process" by Michele Giani at the Advanced Master in sustainable Blue Growth Trieste 25 March 2021.
- Webinar event that involved, in addition to researchers and stakeholders, also students to provide an update on the state of knowledge about national strategies in terms of planning interventions oriented towards decarbonization and carbon neutrality

objectives, highlighting the role of the ICOS network (ICOS Italy virtual conference Nov. 23, 2021: https://www.icos-italy.it/2021/10/save-the-date-23-novembre-ore-1000-webinar-icos/ "Dopo COP26. Scienza, sfide e prospettive per il monitoraggio dei gas a effetto serra").

#### **Co-operation with other RIs**

Some of the Italian ecosystem stations (IT-Cp2, IT-Ren, IT-BFt, IT-Tor, IT-Niv) cooperate with the Long-Term Ecological Research Network (eLTER) and are involved in other National and International projects. In particular, the peri-urban ecosystem sites IT-Cp2 and IT-PCm are involved in the National Project PRIN EUFORICC (*Establishing Urban FORest based solutions In Changing Cities*).

The atmospheric class-2 site of Monte Cimone (IT-CMN) is also an ACTRIS national facility for in-situ reactive gases, aerosol and cloud observations. Moreover, IT-CMN is providing scientific and technical services for trans-national access within the H2020 ATMO-ACCESS project. The atmospheric class-2 site of Lampedusa (IT-Lmp) is also an ACTRIS national facility for aerosol and clouds.

The oceanic station W1-M3A is one of the most important marine infrastructures of the National Research Council of Italy and it is part of the network of deep ocean European observatories and the ERIC EMSO.

## Netherlands

#### **Changes in station network**

#### Cabauw:

The ICOS 14C sampling and the ANSTO 222Rn monitoring (207 and 27m height) continued and the latter flowing into ICOS ATC database starting jan 2022 with historical data starting 2021 as well. The ICOS GHG data from the new infrastructure built in 2020/2021 is the basis for the Cabauw labelling taking place as of 1/10/2021. The flask sampling for QC and ffCO2 is flowing into ICOS ATC as of December 2021. The ICOS flask sampler is used for additional halocarbon analysis on the Medusa system thru Bristol University starting feb 2021 and compared with in-situ Medusa measurements conducted by EMPA starting nov 2021 until summer 2022.

#### Lutjewad

We've made AirCore observations of greenhouse gases on six SkyArrow flights in 2021, 4 in Groningen and 2 in Utrecht. We compared the CO measurements from Picarro G2401 and from G5310 at Lutjewad, and figured out biases in the G2401 CO measurements. At the moment, we are working on an algorithm to correct the CO biases before finalizing the CO product.

#### Loobos

In 2021, we build a new tower close to the tower that was there since 1996. The new tower will be equipped as an ICOS-ETC Class 2 station. Eddy covariance is running since September, radiation since november. The temperature, wind speed, CO2 and H2O profile are currently being built.

220V Power supply cable was installed. A container was located to house tools, computer infrastructure and sensitive equipment.

Partner Utrecht University installed a PT-MRS to measure VOC concentrations and fluxes.

Partner TU Delft is installing a DTS (Distributed Temperature Sensing) to measure temperature and dew point in a profile along the tower.

#### Outreach

- https://www.naturetoday.com/nl/en/nature-reports/message/?msg=28437
- https://www.wur.nl/nl/onderzoek-resultaten/onderzoeksinstituten/environmentalresearch/show-wenr/nieuwe-toren-meet-co2-opname-op-de-veluwe.htm
- https://intranet.wur.nl/umbraco/en/news/new-tower-measures-co2-absorption-on-theveluwe/
- https://www.resource-online.nl/index.php/2021/11/26/tower-measures-forestsbreath/?lang=en

#### **ICOS Carbon Portal Netherlands**

The Ruisdael-delegated employee Remco de Kok has created an update of the data assimilation fluxes for the Global Carbon Project, and provided the synthesis of 6 modeling systems using python Notebooks on the Carbon Portal. This synthesis is part of the publication of our GCP 2021 by Friedlingstein et al (2021). Together with PhD student Auke van der Woude, a new high resolution carbon flux product for Europe was created, to be published in 2022. It will be disseminated through the ICOS Carbon Portal, and the product includes carbon fluxes for the Netherlands, up to 2km in resolution. Creation of this product was coordinated with Ruisdael partners VUA and TNO working on DALES simulations of CO<sub>2</sub>. Simulations with this new product for specifically the Cabauw tower have now started. Data assimilation capacity was contributed to the European Community Inversion Framework (CIF), on which we are co-authored a paper (Berchet et al., 2021). Finally, three Ruisdael researchers (Peters, Krol, Luijkx) taught at the 2021 ICOS winterschool in Hyytiala, with 27 participants from 11 countries.

#### Outreach

Cabauw as well as Lutjewad data has been provided for inverse modelling which resulted in the following paper:

High-resolution inverse modelling of European CH4 emissions using novel FLEXPART-COSMO TM5 4DVAR inverse modelling system (<u>https://acp.copernicus.org/preprints/acp-2022-118/</u>)

Further Cabauw data is being using within the Dutch Ruisdael consortium for e.g., Dales Large-eddy simulations, for Lotos-Euros modelling at TNO and several student projects.

#### **Provided training**

Loobos data was used for BSc/MSc/PhD training:

- Joost Huibers The effect of different scales of heterogeneity on cloud formation, MSc thesis, Wageningen University, 2021
- Yilin Li Drought Response Difference Between Grassland and Forest, MSc thesis, 2021
- Eline Zweers ECOSYSTEM RESPIRATION RESPONSE TO CLIMATE CHANGE IN A SCOTS PINE FOREST IN THE NETHERLANDS, BSc thesis, 2021

• Lieke Lipsch Influence of temperature change on the vegetational CO2 flux in a Scots pine forest in winter BSc thesis 2021

#### **Co-operation with other RIs**

ICOS-NL co-operates with ACRTIS-NL via the Ruisdael Observatory infrastructure

The Cabauw site will become a NF within ACTRIS. Connected to the ICOS in-situ measurements it will become a NF for in situ aerosol and in situ trace gases next to remote sensing. As part of the trace gas measurements NOx and O3 will be measured at the same 4 heights as the GHG ICOS measurements with their own dedicated inlet as well as NH3 directly at three levels. At near ground level (6m) aerosol as well as trace gas measurements take place.

## Norway

#### Highlights

At the Hurdal Terrestrial site, several measurement campaigns following ICOS protocols have been performed in 2021. At all twenty sparse plots (SPs) and the two continuous plots (CPs), tree parameters (height, diameter at breast height, tree species, tree status) with total of ca. 6000 trees have been obtained. At the two CPs, Digital Hemispherical Photography (DHP) using a fisheye lens has been conducted, successfully checked with the ETC and used to get Leaf Area Index (LAI) values at these locations. A region of together 2.88 ha has been scanned for LAI using two hand-held devices in a regular grid. In November 2021, a drone equipped with a Lidar sensor flew over the whole footprint (63 ha), resulting in a high-density Digital Elevation and Canopy Map.

The ICOS Norway annual meeting was held in Bergen (in person) on November 8-9, 2021. All partners were present. During the meeting we held extensive discussions on securing the future financing of ICOS Norway. Several strategies were identified including: increased media presence (contribute with more letters and chronicles to newspapers on the importance and value of carbon research); making sure data are used to fulfil governmental commitments to European and international frameworks (includes identifying requirements); contacting by letter the Ministry for Climate and the Environment; working with carbon cycle researchers in Norway, including outside ICOS, to move towards a Norwegian Carbon Budget. All of these ideas and more are summarized in a shared document at <u>https://fileshare.icos-cp.eu/f/2221762</u>, where they benefit the wider ICOS network in their quest to secure funding.

#### **Changes in station network**

The station on the container vessel *Tukuma Arctica*, which replaces the former vessel *Nuka Arctica* on the same line is operational since January 2021.We have also installed the new reference gases from the ICOS CAL lab.

During 2021, the CO2 instrument at *R/V G.O. Sars*, operated by NORCE, has been updated with new computer and temperature, pressure, and oxygen sensors have been calibrated. New reference gases have been provided from ICOS CAL LAB in Germany, as a service from OTC, and these gas tanks were installed in December. They are larger than the previous ones and are expected to last longer.

A lot of improvements have been made on the pCO2 system on *Trans Carrier*, operated by NORCE, to increase accuracy, data recovery, and reliability. These improvements have been done partly onboard the ship and partly in the lab in Bergen.

In 2021, a new pressure sensor was installed on *R/V Kronprins Haakon* and the piping at the water intake was renewed.

At the Terrestrial site Hurdal, the equipment and all installation items for a class 2 station was completed in 2021. The communication infrastructure was established and an interface setup allowing remote access to all devices, including half-hourly data transfer to the servers of NIBIO. The automatic transfer to the Ecosystem Thematic Centre is pending at the time of writing (February 2022).

On 25<sup>th</sup> May 2021, The ICOS General Assembly unanimously accepted labelling of the Class 2 Atmosphere Station Birkenes Observatory (BIR).

The 'integration' activities in the Norwegian ICOS network "optimize" the a priori fluxes, based on the following information: observed atmospheric methane and CO2 mixing ratios, calculations of atmospheric transport with the Lagrangian particle dispersion model FLEXPART (so-called source receptor relationships), and a statistical (Bayesian) optimization framework. Source-receptor relationships for methane at all European ICOS stations are now calculated operationally on a monthly basis. Newly labeled atmospheric ICOS stations will continuously be added. Products are available from https://shiny.nilu.no/ICOS/.

#### **Co-operation with other RIs**

For the marine domain, we collaborate with the Argo and EMSO infrastructures, ICOS Norway personnel are actively engaged in the Norwegian projects NorArgo2 and NorEMSO, in particular with respect to ensuring that the sensor data are properly calibrated with state of the art seawater CO2 chemistry data.

The atmosphere stations Birkenes and Zeppelin are also ACTRIS sites. The Zeppelin observatory has been operational for over 30 years and is a part of many networks as one of only a few high Arctic measurement stations, and with a mountain top location making it far removed from any local sources, e.g., GAW, AMAP, EMEP, AGAGE.

## Spain

#### Highlights

Spain joined ICOS RI in 2021 with the firm purpose of expanding the ICOS network towards the SW flank with an atmospheric and an oceanic station. Therefore, this first year, all our efforts were focused on starting the labelling process of our two stations: the Izaña atmospheric station Class 2 and the CanOa Vos line as oceanic station Class 1,. In 2021 all necessary actions for preparing or adapting technically the El Arenosillo atmospheric station Class 2, and the ESTOC oceanic station Class 1 to be incorporated into ICOS in 2022. The necessary national agreements and protocols were also initiated between owner institutions, the State Meteorological Agency of Spain (AEMET) and the Ministry of Science and Innovation.

The website of ICOS-Spain network is now available: <u>https://icos-spain.aemet.es</u>

#### **Changes in station network**

• Emilio Cuevas (AEMET) replaced Melchor González (University of Las Palmas de Gran Canaria) as main ICOS national focal point for Spain.

- Stations completed labelling in GA meetings of 2020. The stations were incorporated into ICOS during 2021.
- Pedro Pablo Rivas, person in charge of the greenhouse Gases at the Izaña Atmosheric Research Centre (AEMET) was confirmed as PI of the at Izana ICOS atmospheric station, while Melchor González is the PI of the CanOa Vos line oceanic station.
- A Picarro and LGR analysers were acquired specifically for the ICOS Izaña atmospheric station. Currently, the Atmosphere Thematic Centre (ATC) are testing these instruments.
- Meetings with other Spanish research groups were held in order to recruit new stations for ICOS Spain network.

#### **Provided training**

• Due to the Covid-19 Pandemic, the planned activities with university students were cancelled.

#### **Co-operation with other RIs**

Izaña Observatory is part of the following research networks:

- Actris (AEROSOLS, CLOUDS, AND TRACE GASES RESEARCH INFRASTRUCTURE)
- GCOS (Global Climate Observing System)
- WMO-GAW (Global Atmospheric Watch)
- NDACC (Network for Detection of Atmospheric Composition Change)
- TCCON (Total Carbon Column Observing Network)
- COCCON (Collaborative Carbon column observing network)
- BSRN (Baseline Surface Radiation Network)
- AERONET (AErosol RObotic NETwork)
- MPLNET (Micropulse Lidar NETwork)
- E-GVAP (EUMETNET EIG GNSS water vapour programme)
- PANDORA-PANDONIA

### Sweden

#### Highlights

In early 2021, ICOS Sweden handed in the application "ICOS Sweden infrastructure upgrade and renewal" to the SRC call for Grants for investments in research infrastructures 2021. The positive decision on the outcome came in July 2021. The project includes investments regarding renewal of instruments and upgrading of measuring equipment at the ICOS Sweden infrastructure and complements previously granted resources regarding ICOS Sweden's operations for the period 2021 to 2024. Resources for operation, maintenance, user support and data management are covered by ICOS Sweden's operations for the period 2021 to 2024.

At the stations, the maintenance work to ensure high quality, continuous data had high priority. The risk assessments and detailed workplace strategies have been updated following the Swedish Government's

and Public Health Authority's recommendations regarding measures to reduce the spread of the coronavirus (Covid-19). As in 2020, most study visits from courses have been transferred to digital visits as far as possible. Restrictions concerning visits by master students and interns to the stations have been eased compared to 2020. At most stations, however, despite the restrictions, users could come and perform their fieldwork. The access to SOOP M/S Tavastland which has been operating between Finland and Germany was still limited. To ensure the continuation of the measurements despite these difficulties, maintenance work on board was supported by the GEOMAR Helmholtz Centre for Ocean Research Kiel (Germany). Thanks to this, measurements could be carried out throughout 2021 except for a 4-week period in early 2021 when the ship was in the dockyard for service.

In December 2021, the first call for the ATMO-ACCESS project opened which enables international researchers to visit research facilities which are part of the project through transnational access (TNA). From the Swedish ICOS sites this relates to Hyltemossa. ATMO-ACCESS will deliver a series of recommendations for establishing a comprehensive and sustainable framework for access to distributed atmospheric RIs, ensuring integrated access to and optimized use of the services they provide.

The study Osterwalder et al (2021) presents analyses of pioneering Hg flux measurements at the Baltic Sea coast. It indicates a stronger wind speed dependence for the Hg<sup>0</sup> transfer velocity compared to commonly used parameterizations. The data helps to improve the understanding of air-sea Hg exchange. (Osterwalder, S., Nerentorp, M., Zhu, W., Jiskra, M., Nilsson, E., Nilsson, M. B., et al. (2021). Critical observations of gaseous elemental mercury air-sea exchange. Global Biogeochemical Cycles, 35, e2020GB006742. https://doi.org/10.1029/2020GB006742)

#### **Changes in station network**

From 2021 officially new integrated in ICOS Sweden:

- Class 2 ES station Mycklemossen: Mycklemossen is a hemi-boreal, oligotrophic bog in southern Sweden. It is located approx. 80 km north of Gothenburg and is part of the Skogaryd Research Catchment. The site is run by Gothenburg University.
- Class 1 OS station SOO M/S Tavastland: M/S Tavastland is a roro cargo vessel that travels i.a. the Baltic Sea.

#### **Provided training**

• The stations have been visited physically and digitally by university courses on Bsc, Msc and phd level.

#### **Co-operation with other RIs**

Almost all ICOS Sweden stations are co-located with other research infrastructures. The status in 2021 is listed below. The collaboration at the sites varies but includes shared responsibilities, shared costs and shared staff.

Hyltemossa: ACTRIS RI, ICOS RI, NordSpec

Norunda: ACTRIS RI, ICOS RI, NordSpec

Mycklemossen: ICOS RI, SITES

Svartberget/Degerö: ICOS RI, SITES

Abisko-Stordalen: ICOS RI, SITES

ACTRIS Sweden started in their first funding period as national RI. Within this phase, even Svartberget and Östergarnsholm will become fixed ACTRIS stations.

## Switzerland

#### Highlights

On 1 July 2021, ICOS-CH entered its next funding phase. Financial support by the Swiss National Foundation (ICOS-CH Phase 3, 2021-2025), in-house contributions, and the State Secretariat for Education, Research and Innovation will ensure continued measurements at the two ICOS Class 1 stations Jungfraujoch and Davos. For Phase 3, a new partner from University of Basel carrying out urban eddy covariance measurements since decades joined the ICOS-CH consortium, with the plan to develop one of their urban stations (permanently operated since 2004) as ICOS Associated Site.

ICOS-CH is actively engaged in the ICOS Cities project; Zurich is one of the pilot cities, Basel is part of the extended ICOS Cities network.

The achievements and the relevance of ICOS were reflected in the <u>Geosciences Roadmap</u> and the <u>Biology Roadmap</u> for Swiss Research Infrastructures 2025-2028, where explicit recommendations were made to continue the Swiss contribution to ICOS RI. The roadmaps will serve as input for the future political dialogue and funding decisions beyond the current phase.

#### No changes in station network

#### **Provided training**

• Summer schools, workshops organized by National network

Visit of ETH Board at the ICOS Station Jungfraujoch, 15 July 2021.

Visit of André Kudelski, President of the Innosuisse Board at the ICOS Station Jungfraujoch, 24 July 2021.

In the framework of the Summer School "FORMON - Long-term Forest Monitoring", Mana Gharun (ETH Zurich) offered an excursion to the Davos station, 24 August 2021.

Martin Steinbacher (Empa) taught in the second edition of Global Atmosphere Watch Training and Education Centre's (GAWTEC) webinar series. His training course was entitled "Carbon monoxide in the atmosphere – measurement techniques" (04 November 2021, virtual)

#### **Co-operation with other RIs**

eLTER, ACTRIS, ATMO-ACCESS, RINGO, TreeNet, LWF, Swiss FluxNet, Fluxnet, Fluxnet-CH<sub>4</sub>, SoilTemp, SwissForestLab

The Jungfraujoch station also hosts trace gas and aerosol observations as part of the ACTRIS RI. A joint analysis of ICOS and ACTRIS data from Jungfraujoch was e.g., performed to quantify the contribution of Saharan dust to the ice-nucleating particle concentrations at Jungfraujoch (Brunner et al. 2021).

Martin Steinbacher was invited to join ATMO-ACCESS' Access Evaluation Panel. Members of the panel have the opportunity to promote the advancement of research and technologies addressing essential open questions for atmospheric science and society, and assess transnational access proposals.

Ground-based in-situ CH<sub>4</sub> observations at Jungfraujoch are used along with the total column averaged CH<sub>4</sub> products from the satellite-borne TROPOMI (TROPOspheric Monitoring Instrument) and IASI (Infrared Atmospheric Sounding Interferometer) instruments, from TCCON (Total Carbon Column Observing Network) stations, and balloon-borne in-situ profiles to generate a tropospheric methane profile product. (Schneider et al. 2021)

ICOS-CH members from ETH Zurich, Uni Bern and Empa participated in the RINGO project and contributed to the final report, released in June 2021.

At the Davos site, ecophysiological measurements, particularly automated point dendrometers to detect stem radius changes in a micrometer resolution and biomass inventories, are jointly run with TreeNet, the biological drought and growth indicator network, and LWF, the Long-term Forest Ecosystem Research network in Switzerland (ICP-Forest). New insights when trees actually grow were gained (Zweifel et al. 2021, Etzold et al. 2021).

The SwissForestLab brings together all Swiss researchers on forest-related research, knowledge transfer and outreach. The Davos site is one of its super-sites, since it belongs to many national and international networks. Joint publications, e.g. Trotsiuk et al. 2021, are one of the outcomes, joint teaching and outreach at summer schools and excursions another outlet.

The Davos site is part of the Swiss FluxNet, the Swiss network of active eddy-covariance flux sites. The site has been run since 25 years, being one of the oldest flux sites globally. All its flux and meteorological data are openly accessible via Fluxnet, the global network, and its data have been part of many global synthesis, also in 2021 (e.g. Haesen et al. 2021, Lin et al. 2021, Migliavacca et al. 2021, Zhou et al. 2021). Moreover, certain data have been provided to new global initiatives, such as the Fluxnet-CH<sub>4</sub> (Delwiche et al. 2021) and SoilTemp (Lembrechts et al. 2021).

The Davos site is also part of eLTER, providing access to the site and its data as well as support for exchange students and visitors.

## **United Kingdom**

#### Highlights

- The DY130 cruise to the Northeast Atlantic Ocean, 25<sup>th</sup> March to 14<sup>th</sup> April 2021 (Sue Hartman PSO). The PAP site was a focus for the NASA led EXPORTS project. They deployed 3 gliders and an ARGO float on DY130. The USA team continued monitoring the area through May 2021, using 3 ships at the site.
- The Ridge Hill atmospheric station partners attended the ICOS Atmospheric Thematic Centre training course in September 2021 as part of the labelling process for Ridge Hill. This course provided practical guidance and experience in both the hardware and data processing requirements necessary for Ridge Hill to be accepted as part of the ICOS measurement network.

#### **Changes in station network**

- Stations completing labelling in GA meetings of 2021- Class 1 Ecosystem station Auchencorth Moss & Class 2 Atmosphere Station Weybourne in the UK.
- New station joining the UK ICOS Network; Ridge Hill Atmospheric station.

#### **Provided training**

- Attended the Ocean Thematic Centre intercomparison workshop.
- Supervised an MSc project at the National Oceanography Centre, related to ICOS data. Dissolved Oxygen and Biochemical variability at the PAP site in the Northeast Atlantic Ocean.
- Looking to advertise for a new PhD student to work with the PAP and SOOP CO2 data. 'Temporal variability of the carbon system across the Atlantic Ocean; causes and implications.

#### **Co-operation with other RIs**

- PAP-SO is an EMSO station. PAP-SO is also in iAtlantic, AtlantECO, MINKE and iFADO projects.
- Ridge Hill atmospheric station has operated since 2012 as part of the UK's Deriving Emissions related to Climate Change networks. It also has a strong link to the Advanced Global Atmospheric Gases Experiment (AGAGE) network, via the involvement of the University of Bristol in trace gas measurements at Mace Head, Ireland. Since February 2021, Ridge Hill data have simultaneously undergone post-processing according to AGAGE and ICOS specifications. This will allow direct comparison between the post-processing procedures prescribed by the 2 networks.

## **Annex 1: ICOS Publications and citations**

Total of 1697 scientific articles are listed in the Carbon portal, 198 of which with year 2021.

https://www.icos-cp.eu/science-and-impact/society-impact/references

The number of citations of these articles has been growing in an accelerating speed, see graph below.

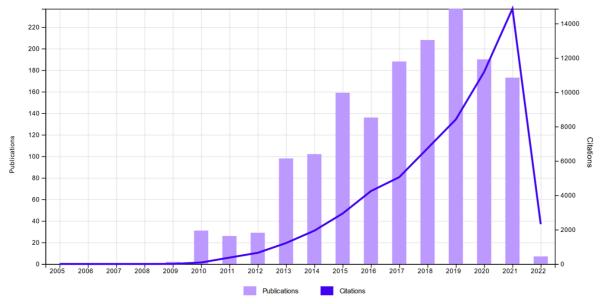


Figure 9. ICOS related articles (bars) and citations to them (line) from 2005

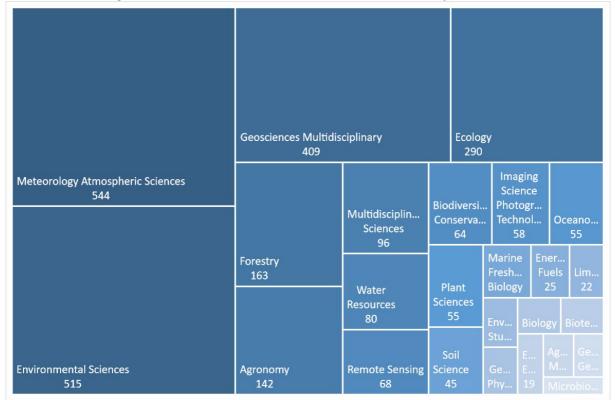


Figure 10. Topic categories of ICOS related articles

## **Annex 2: Data for KPIs**

## Usage of ICOS data in educational tools and education activities (KPI 27)

	TC, CP and HO educational or training activities
ATC	One three-day online training, PIs/Staff from Germany, Italy, UK and Spain attending. All the initial training requested for new ICOS comers and step 2 labelling have been provided by ATC.
ATC	ATC will continue to offer standard training at ATC in order to answer the demand of new incomers and also to deal with the technical staff turnover. ATC is also working on webinar dedicated to new specific topics (instrumentation, sampling setup) and refresh on topics already dispensed in the initial training session.
ETC	Eight Instruction documents have been revised, clarified and updated in 2021, and 19 BADM templates for the ancillary data revised and improved. A new instruction document for ancillary data collection for shrublands was developed.
ETC	The ETC coordinated field campaigns done in coordination with the PIs of the ICOS stations for the evaluation of a different method for the GAI measurement using below canopy PAR sensors under canopy.
отс	Gas bottle calibration: In 2020 the OTC started together with the ICOS flask and calibration laboratory a support scheme for the ocean community. In 2021 the first certified (WMO traceable) gas bottles were delivered to stations, and by the end of 2021 more than 25 bottles were delivered to the stations.
отс	Sub-standard preparation: Due to the pandemic, the supply of Certified Reference Material (CRM) stopped completely. This became a huge problem for marine carbon laboratories all around the world. In collaboration with GEOMAR Helmholtz Centre for Ocean Research Kiel in Kiel/Germany the IOCS OTC prepared more than 400 bottles (500 and 250 mL) of a sub-standard based on seawater from the North Atlantic Ocean. The bottles were distributed to ICOS labs to guarantee their operation.
ЕТС, ОТС, АТС, СР, НО	ICOS Discussion server in Discord was set up by Ecosystem MSA to enable fast info sharing, connecting with all ICOS PIs, TCs, CP and HO and providing fast support to technical problems in all stations across domains.
СР	ICOS "summer" school themed "Challenges in measurements of greenhouse gases and their interpretation" was organised in Hyytiälä in December 2021
СР	Carbon Portal hosted a webinar series of 5 webinars on to find, preview and use ICOS data using the CP Data Portal and Jupyter Notebooks developed in CP
СР	INES seminar at Lund University "Jupyter Notebooks in Education - examples using ICOS data" (presenter: Karolina Pantazatou)
СР	ENVRI International Winter School "VREs, Data Analysis & Visualisation" (presenters: Claudio D'Onofrio, Ute Karstens, Karolina Pantazatou, Ida Storm) on 13 January 2021
СР, НО	Hackathon "Hack the Arctic", 12-14 March 2021
	Total: 1 new training tool and 11 activities from TCs, CP and HO

	NN educational or training activities
BE	1 PhD thesis (Miro De Mol) and 5 MSc theses (Freke van Damme, Hanna Mertens, Matthieu Delespesse, Clara Cravatte, Florian Vanden Brande) completed using ICOS data, 1 post-doc working with ICOS data (Wafa Chebbi)
СН	In the framework of the Summer School "FORMON - Long-term Forest Monitoring", Mana Gharun (ETH Zurich) offered an excursion to the Davos station, 24 August 2021.
СН	Martin Steinbacher (Empa) taught in the second edition of Global Atmosphere Watch Training and Education Centre's (GAWTEC) webinar series. His training course was entitled "Carbon monoxide in the atmosphere – measurement techniques" (04 November 2021, virtual)
CZ	Annually on average of 40 lectures given either to the general public or to specific groups such as companies' managers and municipalities
CZ	4 PhD theses completed (Mensah Caleb, Ondřej Nezval, Michal Bellan, Jana Rosíková) using or related to ICOS data
DE	Lecture for GAWTec / Young Earth System Scientists community webinar series on GHG in 2020/2021 presenting ICOS activities ( <u>https://www.yess-community.org/gawtec-</u> webinar-series-2020/) by DWD
DE	Eddy Covariance Winter School for African students, technicians and postdocs, 24 26.11.21, presenting ICOS methodologies ( <u>https://www.emsafrica.org/courses/past-</u> <u>course-eddy-covariance-flux-measurements-intensive-course</u> ), hosted and organized by Thünen Institute
DE	1 PhD thesis (Kanisios Mukwashi) and 2 master theses (Peter Miersch, V. Kuch) completed using or related to ICOS data
DK	1 PhD thesis (Johan Scheller) completed using ICOS data from Zackenberg station.
FI	ICOS "summer" school organised in Hyytiälä in December 2021
FI	6 MSc theses (Arola, A., Strömberg, J., Frühauf, Y., Laasonen, A., Haverinen, S., Kuuri- Riutta, O.) completed using or related to ICOS data
FR	3 sessions of distant (due to COVID restriction) training for the technical staff of stations. Each meeting gathered about 40 people. Themes: "How to fill BADM?", "Tips for maintenance of EC system", "Data exchange between site and the ETC".
FR	A French-speaking web forum was set up to foster exchanges and keep track of the collective knowledge.
FR	4 PhD dissertation theses (Chandra, V., Pique, G., Dare-Idowu, O., Pageot, Y.) and 6 master theses completed using or related to ICOS data
GB	1 MSc project (Dissolved Oxygen and Biochemical variability at the PAP site in the Northeast Atlantic Ocean) supervised related to ICOS data at the National Oceanography Centre
IT	Several lectures given in master level courses about ICOS activities during the year, students also participating in ICOS Italy virtual conference on Nov. 23, 2021

NL	2 MSc theses (Joost Huibers, Yilin Li) completed using or related to ICOS data. In addition, Loobos station data was used for BSc/MSc/PhD training.	
SE	ICOS stations have been visited physically and digitally by university courses on Bsc, Msc and PhD level.	
	Total educational or training activities by NN:	
	• 49 educational or training events	
	• 11 PhD theses	
	• 22 MSc theses	
	• 1 post-doc	

#### Summary for KPI 27:

60 educational or training events 11 PhD theses 22 MSc theses 1 post-doc 1 new training tool

#### **Facilitation of scientific initiatives (KPI 28)**

1.	<b>Warm winter 2019/2020 initiative</b> explicitly integrates alterations in greenhouse gas concentrations and fluxes from all three ICOS domains analysing the seasonal anomaly in 2019/2020 followed by the COVID-19 lockdown. The data release includes data from 73 stations, 49 of these ICOS stations.
2.	<b>Horizon MSCA Doctoral Network proposal</b> (CarboAdvance) was submitted 16 November 2021, Coordinated by Ivan Mammarella (University of Helsinki). Proposal brought together scientific ideas, researchers and institutes across all ICOS domains.
3.	<b>pCO2 intercomparison</b> : Flanders Marine Institute (VLIZ) with support from OTC and Ocean MSA hosted an international pCO2 sensors/systems inter-comparison activity from 28 June until 11 July 2021 which was conceived as a once in ten years landmark calibration activity. In total of 29 instruments (18 different types of instruments) participated in the experiment. This has attracted interest from renounced international groups working on Marine Inorganic Carbon Research.
	Total for KPI 28: 3 scientific initiatives facilitated

#### **Participation in events of regional or global relevance (KPI 34)** List of Main ICOS National Network Meetings

Country	Meeting	Time	Place
BE	ICOS study day: Update network, introduction CongoFLux tower. Survey 'ICOS BE: evaluation of the past five years and envisioning the future' and roundtable discussion to discuss survey results.	1 April 2021	Online

BE	ICOS-WB2 kick-off meeting. Presence of a	04/11/2021	
	representative from the Walloon Region, of ICOS-WB partners and staff members as		
	well follow-up committee members.		
СН	ICOS Davos spring meeting	13 April 2021	virtual
СН	HFSJG (High Altitude Research Stations Jungfraujoch and Gornergrat) Users Meeting	28 May 2021	virtual
СН	ICOS-CH Annual Meeting 2021	22 September 2021	Zurich
ES	Teleconference of ICOS-Spain managers	March 3, 2021	Online
ES	Teleconference of ICOS-Spain and future members. October 26, 2021.	March 3, 2021	Online
FI	ICOS-Finland annual meeting	26 November	
FR	ICOS France meeting	October 12 to 14	Reims,
			Champagne- Ardenne region
IT	Meetings of the JRU ICOS-Italy	15 April 2021; 19 November 2021	Online
IT	Meetings of the Fixed Ocean Station ICOS- Italy	27 May 2021; 6 December 2021	Online
NO	ICOS Norway annual meeting	8-9 November 2021	Bergen
NO	ICOS Norway GA	November 2021	Online
	Total: 13 NN meetings		

#### List of Main Events Organised or Co-organised by ICOS National Network

Country	Event
BE	Vielsalm labelling event (27/10/2021). Presence of the Minister of Agriculture of the Walloon Region (who funded the ICOS-WB project), institution authorities, members of the ICOS National Network staff and of ICOS ETC.
СН	EGU General Assembly 2021 (19-30 April 2021, virtual): Mana Gharun (ETH Zurich) convened the session "Bridging understanding of carbon and water fluxes from leaf to continent with observations and simulations" (BG3.18).
СН	EGU General Assembly 2021 (19-30 April 2021, virtual): Simone Pieber (Empa) convened the EGU early career scientist round table "Great Debate 5" discussion on "Bullying in Academia – towards creating healthy and safe working environments" (GDB5).
СН	Swiss GCOS/GAW Symposium on Earth System Cycles (13-14 September 2021), virtual, Martin Steinbacher was member of the Scientific Programme Committee.
СН	Swiss Geoscience Meeting 2021 (19-20 November 2021, virtual): The session "Atmospheric Composition and Biosphere-Atmosphere Interactions" (Session 17) was co-chaired by Martin Steinbacher (Empa) and Mana Gharun (ETH Zurich).

DE, FI, SE, NO	3rd ICOS Nordic Symposium, 2325.11.2021. Organized online by ICOS Finland, ICOS- Sweden, ICOS-Denmark and ICOS-Norway. 170 registered participants. Website: https://www2.helsinki.fi/en/conferences/3rd-icos-nordic-symposium	
FI	Finnish Ecosystem Science meeting: ICOS, eLTER and AnaEE networks, 46.5.2021 organized online together with eLTER and AnaEE RIs. 150 registered participants. Website: <u>https://www2.helsinki.fi/en/conferences/finnish-ecosystem-science-meeting</u>	
IT	European Researchers' Night - Science Together Net initiative, in Lampedusa, September 2021. Seminars and experiences on climate and greenhouse gases on 24 September 2021.	
IT	ICOS Italy virtual conference, 23 November 2021: <u>https://www.icos-italy.it/2021/10/save-the-date-23-novembre-ore-1000-webinar-icos/</u> "Dopo COP26. Scienza, sfide e prospettive per il monitoraggio dei gas a effetto serra").	
IT	Online seminar on climate and greenhouse gases measurements for the Protected Marine Area of Pelagie islands, 9 June 2021.	
NL	Official opening ceremony of the new flux tower in the Class 2 Ecosystem station Loobos (12 <sup>th</sup> November 2021, on site).	
	Total: 11 events organised or co-organised by NN	

#### List of Main Events Attended by ICOS National network staff

	Workshops and conferences attended	Time	Place
BE	CCVS Workshop 13 – 15 October 2021 – virtual meeting		
BE	TCCON / NDACC-IRWG / COCCON annual meeting (June 2021) – virtual meeting		
СН	Childrens´University, University of Zurich	10 March 2021,	virtual
СН	NOAA's Virtual Global Monitoring Annual Conference eGMAC)	25-28 May 2021	virtual
СН	9th Scientific Conference of ICP Forests	7 June 2021	virtual
СН	Kangaroo goes Science	10 June 2021	virtual
СН	GAW Quadrennial Symposium 2021	28 June–02 July 2021	virtual
СН	EGU General Assembly 2021	19-30 April 2021	virtual
СН	Swiss GCOS/GAW Symposium on Earth System Cycles	13-14 September 2021	virtual
СН	Swiss Geoscience Meeting 2021	19-20 November 2021	virtual

CZ	FORECOMON 2021 – The 9th Forest Ecosystem Monitoring Conference	7-9 June 2021	Birmensdorf, Switzerland
	https://forecomon2021.thuenen.de/		
CZ, SE	Annual meeting of European Geosciences Union EGU	19-30 April	Virtual
FI	Supercomputer modeling of climate system - seminar, Moscow State University		
FI	ACCC and Finnish Atmospheric Science Network Seminar, Helsinki		
FI	EcoClimate workshop, Oulanka research station / remote, Finland		virtual and in person
FR	Climate forum, with the loan of our set of ICOS- scape exhibition panels	October	Epernayin
FR	Science festival	October	Versailles Saint- Quentin-en- Yvelines Observatory
IT	ILEAPS Lite virtual conference held on (The P.I. of IT- Cp2 S. Fares was convener "Urban forests and ecosystem services").	25 March 2021	
IT	JRC-ENEA Online seminar on the relationship between air pollution and the spread of the SARS COV-2 pandemic,	24 June 2021.	
IT	Ocean Acidification Week 2021- A virtual multi-day forum to highlight different aspects of ocean acidification research and initiatives from around the world –	13-17 September 2021.	
	Total: 20 events attended by NN staff	1	1

	Presentations given	Time	Place
BE	ATMOS 2021 – Mahesh Kumar Sha gave a talk titled "Ground-Based Remote Sensing FTIR Networks, their Complementarities and Usefulness for the Validation of Satellite GHG Products" at the ATMOS 2021 - ESA Atmospheric Science Conference	22-26 November	virtual
ES	Curbelo-Hernández, D., M. González-Dávila, A.G: González, D. González-santana, J.M. Santana- Casiano. Seasonal and spatial variability of the CO2 system parameters in the Northeast Atlantic based on measurements from a surface ocean observation platform. EGU General Assembly 2021. Viena, Austria. April 19-30, 2021.		

ES	Curbelo-Hernández, D. M. González-Dávila and J.M. Santana-Casiano, Temporary evolution of the carbon dioxide system in a Northeast Atlantic transect. XX Seminario Ibérico de Química Marina (SIQUIMAR 2020).	July 1-3, 2021	Barcelona, Spain
IT	Presentation of the Italian ICOS network at the Conference of CNR-DSSTA "Il ruolo del CNR nelle sfide ambientali del New Green Deal"	18-19 March 2021.	
ІТ	Presentation of the Italian ICOS marine stations at the workshop JRU-EMSO Italia "Verso una visione 4-D dell'oceano: sinergie e integrazione delle iniziative italiane",	6-7 October 2021	
NO	Platt, S.M., Arctic Methane, Royal Society Meeting on "Rising methane: is warming feeding warming?", Online,	04.10.2021- 04.10.2021	Virtual
NO	Platt, S.M. Atmospheric composition in the European Arctic and 30 years of the Zeppelin Observatory, Ny- Ålesund, Ny-Ålesund Flagship Meeting, Oslo, 2021		Oslo
NO	Thompson, R. L., Greenhouse gases: What are they, how their levels have changed and why?, Lecture at University of Luxembourg, Luxembourg,	09.12.2021- 09.12.2021	Luxembourg,
NO	Thompson, R. L, Extreme weather in Europe 2018 – a natural experiment to examine the effect on methane emissions, Royal Society Meeting on "Rising methane: is warming feeding warming?"	04.10.2021- 04.10.2021	Online
NO	Thompson, R. L, Recent trends in CH4 and N2O and their role as climate forcers, 3rd ICOS Nordic Symposium, Online,	23.11.2021- 25.11.2021	
	Total: 10 presentations given by NN staff		

	High-level station visits	Time	Place
BE	Inauguration CongoFlux with visitors from the Belgian Embassy, the ambassador of the European Union and the governor of the Tshopo Province.	January 2021	CongoFlux
BE	Visit of the UK ambassy to the Congoflux tower.	September 2021	Congoflux
СН	Visit of ETH Board at the ICOS Station Jungfraujoch	15 July 2021	Jungfraujoch
СН	Visit of André Kudelski, President of the Innosuisse Board at the ICOS Station Jungfraujoch	24 July 2021	Jungfraujoch

	Attendance on events or presentations given	Time	Place	
НО	Finnish Ecosystem Science Meeting: keynote lecture given by Werner Kutsch	4. – 6.5.2021		
НО	InternationalConferenceonResearchInfrastructuresPlenary:Marshalling global research infrastructuretoaddressemergencies:Incorporatingresilienceandagilityinresearchinfrastructureplanning,financing,andoperations	1. – 3.6.2021		
НО	Reception of the Hungarian Ambassador visiting Hyytiälä station	18.6.2021	Hyytiälä	
НО	Australia-Europe RI cooperation on Environmental Science: poster presentation			
НО	COP 26 UNFCCC – Earth Information Day		Glasgow	
НО	ESFRI Exchange of Experience Meeting: presentation on Socio-Economic impact, RI services and access to data	15.11.2021		
НО	Lecture on Carbon fluxes in sub-Saharan Africa (University of Helsinki)	14.4.2021		
НО	Lecture on Financial Management of the distributed research infrastructure ICOS (University degli Study di Milano Bicocca)	20.4.2021		
отс	G7 Statements around the Future of the Seas and Oceans 2021			
отс	Scoping meeting of NACO, Canadian Initiative on North Atlantic Carbon Observatory	December 2021		
OTC, Ocean MSA	JPI (Joint programming Initiative) meeting and workshop attended by OTC, Ocean MSA chairs and some station PIs			
	Total: 11 events attended by HO or TC staff			

#### List of Main Events Attended by ICOS Head Office and/or Thematic Centres

#### Summary for KPI 34:

#### **13 National Network meetings**

#### 11 organised events

41 events attended

## **Annex 3: Availability of ICOS data**

In the heat maps below, a grey box notates weeks, where 100% of the expected data has been available from that station. Shades of red mark partially covered weeks, and in white areas that station has not yet produced ICOS data.

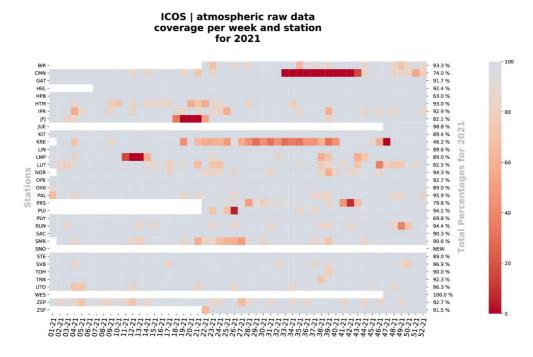
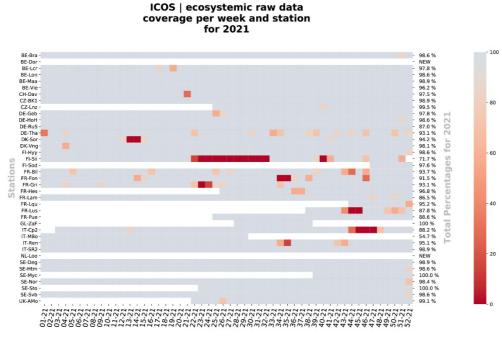
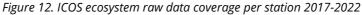


Figure 11. ICOS atmosphere raw data coverage per station 2017-2022





# Annex 4: List of stations and their co-location with other RIs

Name	Domain	Class	Location	Member	eLTER	ACTRIS	Other*	Notes
La Reunion	Atm	2	FR	BE+FR	x	х		
Brasschaat	Eco	1	BE	BE	х			
Maasmechelen	Eco	1	BE	BE	x			
Dorinne	Eco	2	BE	BE				
Lonzee	Eco	2	BE	BE	x			
Vielsalm	Eco	2	BE	BE	х	х		
CongoFlux	Eco	Associated	CD	BE				
Lochristi	Eco	Associated	BE	BE				
<b>BE-FOS-Thornton Buoy</b>	Ocean	1	BE	BE	х		x	LifeWatch
BE-SOOP-Belgica	Ocean	1	BE	BE				
BE-SOOP-Simon-Stevin	Ocean	1	BE	BE			x	LifeWatch
Jungfraujoch	Atm	1	СН	СН		х		
Davos	Eco	1	СН	СН	х			
Křešín u Pacova	Atm	1	CZ	CZ		х		
Lanzhot	Eco	1	CZ	CZ			х	Danubius
Bily Kriz forest	Eco	2	CZ	CZ	x			
Trebon	Eco	Associated	CZ	CZ	х		х	ANAEE
Gartow	Atm	1	DE	DE				
Hohenpeissenberg	Atm	1	DE	DE		х		
Karlsruhe	Atm	1	DE	DE				
Lindenberg	Atm	1	DE	DE		х		
Ochsenkopf	Atm	1	DE	DE				
Schauinsland	Atm	1	DE	DE				
Steinkimmen	Atm	1	DE	DE				
Helgoland	Atm	2	DE	DE				
Jülich	Atm	2	DE	DE		х		IAGOS
Torfhaus	Atm	2	DE	DE				
Westerland	Atm	2	DE	DE				
Zugspitze	Atm	2	DE	DE		х		
Fendt	Eco	1	DE	DE				
Gebesee	Eco	1	DE	DE				
Hohes Holz	Eco	1	DE	DE	х			
Selhausen Juelich	Eco	1	DE	DE	x			
Tharandt	Eco	1	DE	DE				
Braunschweig	Eco	Associated	DE	DE				
Graswang	Eco	Associated	DE	DE				
Grillenburg	Eco	Associated	DE	DE				
Grosses Bruch	Eco	Associated	DE	DE	x			
Hainich	Eco	Associated	DE	DE				

Hartheim	Eco	Associated	DE	DE				
Hetzdorf	Eco	Associated	DE	DE				
Kienhorst	Eco	Associated	DE	DE				
Klingenberg	Eco	Associated	DE	DE				
Mooseurach	Eco	Associated	DE	DE				
Oberklenkendorf	Eco	Associated	DE	DE				
Rollesbroich	Eco	Associated	DE	DE	x			
Schechenfilz Nord	Eco	Associated	DE	DE	~			
Wustebach	Eco	Associated	DE	DE	x			
DE-FOS-CVOO	Ocean	1	DE	DE	~			
DE-FOS-Hausgarten	Ocean	1	DE	DE	x			
DE-SOOP-Atlantic Sail	Ocean	1	DE	DE	^			
DE-SOOP-Finnmaid	Ocean	1	DE	DE	1			
DE-SOOP-Polarstern	Ocean	1	DE	DE				
			DE	DE		× ×		
Station Nord	Atm	2				Х		
Soroe	Eco	1	DK	DK				
Voulundgaard	Eco	1	DK	DK				
Zackenberg Fen	Eco	2	GL	DK				
Disko	Eco	Associated	GL	DK				
Gludsted Plantage	Eco	Associated	DK	DK				
Kobbefjord	Eco	Associated	GL	DK				
Nuuk Fen	Eco	Associated	GL	DK				
Risoe	Eco	Associated	DK	DK				
Skjern	Eco	Associated	DK	DK				
Zackenberg Gras	Eco	Associated	GL	DK				
Izana	Atm	2	ES	ES		х	Х	
CanOA VOS-line	Ocean	1	ES	ES				
Hyytiälä	Atm	1	FI	FI	х	х	х	ANAEE
Pallas	Atm	1	FI	FI	х	х	х	ANAEE
Puijo	Atm	2	FI	FI		х		
Utö - Baltic sea	Atm	2	FI	FI		х	х	Jerico
Sodankyla	Eco	1	FI	FI				
Lompolojankka	Eco	2	FI	FI	х	х	х	ANAEE
Siikaneva	Eco	2	FI	FI	х			
Kenttarova	Eco	Associated	FI	FI	х	х		
Kuivajarvi	Eco	Associated	FI	FI	х			
Kumpula	Eco	Associated	FI	FI				
Lettosuo	Eco	Associated	FI	FI				
Varrio	Eco	Associated	FI	FI	х	х	х	ANAEE
Observatoire pérenne de								
l'environnement	Atm	1	FR	FR				a.k.a Bure
Saclay	Atm	1	FR	FR				
Trainou	Atm	1	FR	FR				
Puy de Dôme	Atm	2	FR	FR				
Fontainebleau-Barbeau	Eco	1	FR	FR				
Hesse	Eco	1	FR	FR				
Lamasquere	Eco	1	FR	FR				

Bilos	Eco	2	FR	FR			х	ANAEE
Font-Blanche	Eco	2	FR	FR				
Grignon	Eco	2	FR	FR				
Laqueuille	Eco	2	FR	FR				
Lusignan	Eco	2	FR	FR				
Puechabon	Eco	2	FR	FR			х	ANAEE
Aurade	Eco	Associated	FR	FR	x			
Col du Lautaret	Eco	Associated	FR	FR	x		х	ANAEE
Estrees-Mons A28	Eco	Associated	FR	FR			~	
Guyaflux	Eco	Associated	GF	FR				
La Guette	Eco	Associated	FR	FR				
Mejusseaume	Eco	Associated	FR	FR				
Montiers sur Saulx	Eco	Associated	FR	FR				
Nouragues	Eco	Associated	GF	FR				
Toulouse	Eco	Associated	FR	FR		x		
FR-SOOP-France-Brazil	Ocean	Associated 1	FR	FR		^		
Ridge Hill tower	Atm	2	GB	GB				
Weybourne Atmospheric	Aun	2	GD	GD				
Observatory	Atm	2	GB	GB				
Auchencorth Moss	Eco	1	GB	GB				
UK-FOS-PAP	Ocean	1	GB	GB			Х	EMSO
UK-FOS-Western Channel								
Observatory	Ocean	1	GB	GB				
UK-SOOP-UK-Caribbean	Ocean	1	GB	GB				
Lampedusa	Atm	2	IT	IT		х		
Monte Cimone	Atm	2	IT	IT		х		
Plateau Rosa	Atm	2	IT	IT				
Borgo Cioffi	Eco	1	IT	IT				
Castelporziano2	Eco	1	IT	IT	х			
Monte Bondone	Eco	2	IT	IT				
Renon	Eco	2	IT	IT	x			
Arca di Noe - Le Prigionette	Eco	Associated	IT	IT				
Bosco Fontana	Eco	Associated	IT	IT	х			
Lison	Eco	Associated	IT	IT				
Nivolet	Eco	Associated	IT	IT	x			
Parco Urbano di								
Capodimonte	Eco	Associated	IT	IT				
Torgnon	Eco	Associated	IT	IT	х			
IT-FOS-PALOMA	Ocean	1	IT	IT				
IT-FOS-E2M3A	Ocean	2	IT	IT				
IT-FOS-Miramare	Ocean	2	IT	IT				
IT-FOS-W1M3A	Ocean	2	IT	IT			Х	EMSO
lspra	Atm	2	IT	JRC				
San Rossore 2	Eco	2	IT	JRC				
Cabauw	Atm	1	NL	NL		х		
Lutjewad	Atm	2	NL	NL				
Loobos	Eco	2	NL	NL				

Zeppelin	Atm	1	NO	NO		х	
Birkenes Observatory	Atm	2	NO	NO		х	
Hurdal	Eco	2	NO	NO			
NO-SOOP-G.O.Sars	Ocean	1	NO	NO			
NO-SOOP-Tukuma Arctica	Ocean	1	NO	NO			
NO-SOOP-Kronsprins Haakon	Ocean	2	NO	NO			
NO-SOOP-Trans Carrier	Ocean	2	NO	NO			
Hyltemossa	Atm	1	SE	SE			
Norunda	Atm	1	SE	SE		х	
Svartberget	Atm	1	SE	SE			
Abisko-Stordalen Palsa Bog	Eco	2	SE	SE	х		
Degero	Eco	2	SE	SE			
Hyltemossa	Eco	2	SE	SE		х	
Mycklemossen	Eco	2	SE	SE	х		
Norunda	Eco	2	SE	SE			
Svartberget	Eco	2	SE	SE	х		
SE-MFT-Östergarnsholm	Ocean	1	SE	SE			
SE-SOOP Tavastland	Ocean	1	SE	SE			

32 28 15 **total**