ICOS Annual Report 2022

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ICOS/GA18/2023/07

Contents

ICOS RI ANNUAL REPORT

2022 Highlights of ICOS Research Infrastructure

ICOS Science conference – first time as hybrid

ICOS Science conference in Utrecht 13-15 September featured 118 poster-, 124 oral presentations and 11 Plenary talks. These presentations covered 22 Themes and they were divided into 21 sessions across the three conference days. The conference had altogether 423 attendees of which 120 participated remotely and total 303 participants were present onsite of which 14 were organisers and 15 exhibitors. The fully hybrid mode did not only allow remote participation, it also allowed in situ participants to listen to recorded sessions afterwards, and session chairs to pre-select the most interesting questions to the presenter.

ICOS input to COP27

As ICOS has the status of an observer intergovernmental organization to the UNFCCC, it took part in the 2022 United Nations Climate Change Conference, also known as COP27, in Sharm el-Sheikh, Egypt 7.–18.11.2022. The goal was to highlight the need for a global observation network to have a scientific base for decisions, and to remind of the need for more drastic climate action.

ICOS hosted a side event: "Systematic observation of greenhouse gases (GHG) to support climate action in cities and regions". This side-event was the opportunity to showcase the activities performed in the PAUL (ICOS Cities) and KADI projects. In addition, ICOS scientists participated in side-events hosted on the European, the Benelux and the WMO pavilions. ICOS also presented a poster during the Earth Information Day (9.11.2022).

ICOS data crucial to estimate methane outflow from Nord Stream

Unprecedented leak of methane was observed at Baltic sea due to the damaged Nord Stream gas lines. The methane emissions were confirmed by ICOS ground-based observations from several stations in Sweden, Norway, Finland and even UK and Western France. Satellites were unable to detect the emission leaks, due to the presence of clouds. Thus, the ICOS data were used by several inverse modelling groups to calculate the amount of methane emitted to the atmosphere. This showcased a real-life application of the importance and benefits of in situ GHG measurements and ICOS' near-real time data release. HO communications prepared a press release and the following media attention was the highest to-date (1.22K media hits). The case also demonstrated the capabilities of the ICOS community to explain an unexpected situation as it unfolded.

First issue of European Carbon Bulletin FLUXES

FLUXES, the European Greenhouse Gas Bulletin is a new publication by ICOS, which aims at highlighting climate issues to an audience of policymakers, policy advisors, and climate journalists.

The first volume of FLUXES which was prepared 2022, focused on regional and year-over-year changes in carbon sinks in Europe. These changing sinks highlight the need to reduce emissions further in order to reach carbon neutrality targets.

Ireland and Greece decided to join ICOS

Greece and Ireland joined ICOS, allowing for a significant geographical extension of the network both to the North-West and South-East of the continent. The addition of 14 new stations (10 in Ireland and 4 in Greece) represents an increase of almost 10 % of the total network.

Strong ICOS contributions to ICRI

ICOS Director General contributed with three presentations to the International Conference on Research Infrastructures in Brno (one in the main program and two in side events). The conference was furthermore used to deepen international cooperation, particularly with US (NEON) and South Africa (SAEON).

Cross-RI co-operation in GEORGE project

ICOS ERIC coordinated a successful Horizon Europe funding proposal with EMSO and EURO ARGO for GEORGE - NEXT GENERATION MULTIPLATFORM OCEAN OBSERVING TECHNOLOGIES FOR RESEARCH INFRASTRUCTURES. The project starts 1.1.2023, see more in Projects section (p.20)

KPI summary

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

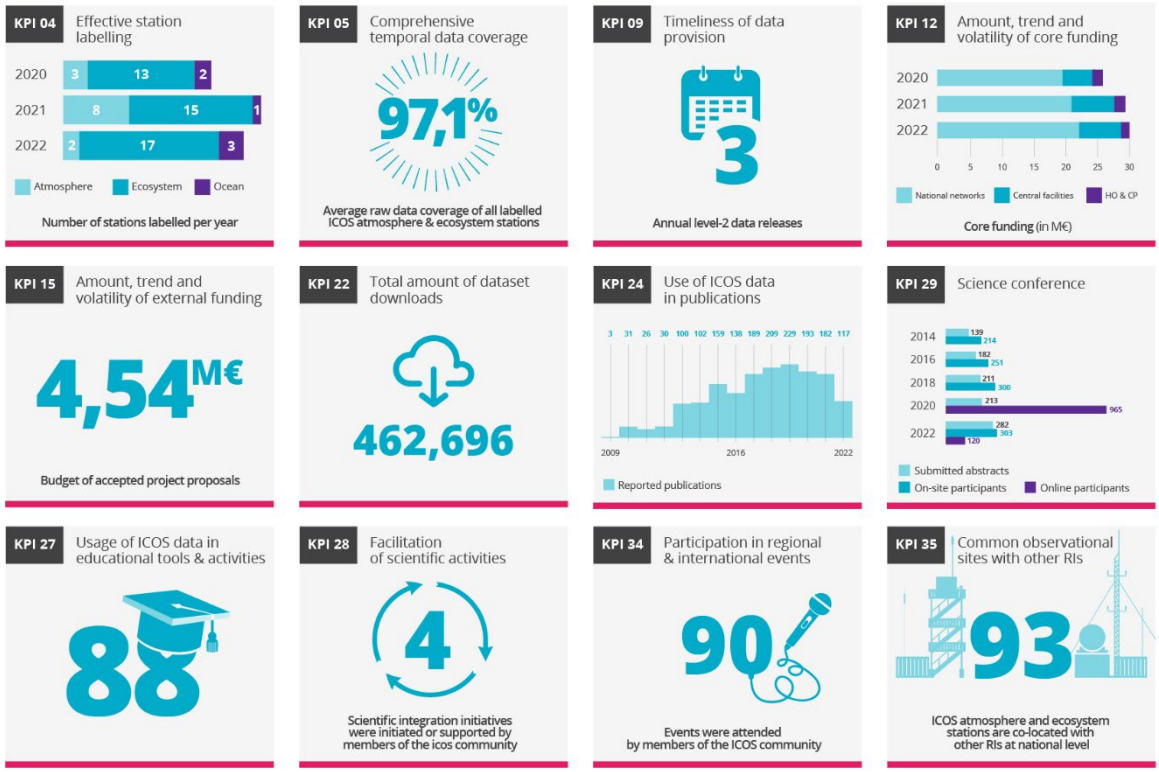


Figure 1 ICOS Key Performance Indicators, KPIs 2023

Co-operation with other infrastructures

The most important co-operation between infrastructures happens on station level. Having stations of two different networks at same location or near to each other has important scientific benefits and can lead to significant savings in electricity and data connections and especially in travel arrangements of maintenance technicians and other staff. However there are risks of having certain types of instruments too close to each other, e.g. the radiocarbon analysis at ICOS Class 1 Atmosphere stations can be disturbed by certain types of ACTRIS instrumentation. The co-located stations are listed in Annex 1.

As Chair of the Board of European Environmental Research Infrastructures (BEERI), ICOS Director General represented the ENVRI community in several events organised by the European Commission and by the ESFRI on future funding and the future landscape of research infrastructures.

A working group between the ICOS and ACTRIS Head Office teams and has been tasked by Academy of Finland to annually report co-operation. Their report is in Annex 3.

Director General and head office

Progress in the regular tasks

General Assembly coordination

During the year 2022 ICOS had two General Assembly meetings. Spring meeting was held in Prague, and the autumn meeting in Madrid. An Info Day was included to both of the GA meetings.

In the spring meeting, a new Chair (Christian Plass-Dülmer) and a new member to the Scientific Advisory Board (Philippe Ciais) were elected. ICOS Management Plan was approved and nearly all financial documents, except document ICOS RI Financial Report. Ocean thematic centre informed about the mistake in the numbers. The centre sent updated numbers in July and the document has been corrected. General Assembly also asked Head Office to prepare two or three scenarios for the 3rd five-year financial period (2025-2029) with cost estimates to be presented in the November General Assembly meeting. The SAB-chair participated online.

Greece was approved to join to ICOS ERIC as of the beginning of 2023 by a written procedure of the General Assembly.

In the November meeting a new vice-Chair (Ritva Dammert) was elected. An other new ICOS ERIC member country (Ireland) was also approved to join as of the beginning of year 2023. To further improve financial stability, the Director General suggested a “Financial Info Day” and General Assembly decided to have an extra meeting in February 2023. The meeting topics are related to the scenarios for the 3rd five-year period, and the General Assembly asked the Head Office to provide three scenarios with the funding increase 0%, 8.5% and 17%. Three different scenarios for relation between station-based contribution and host-contribution was also asked. The ICOS Ethical Guidelines were approved. The Work Plan 2023 was approved. The amounts of membership contribution and contribution towards Central Facilities were not confirmed due to an unclarity with the new Finnish stations. The decision about national stations funding was made in February 2023.

RI Committee management

The RI Committee, formed by representatives from the Head Office, Carbon Portal, Central Facilities and Monitoring Station Assemblies, had a-three-day online meeting (“fake-to-fake”) in spring and a real face-to-face meeting in October in Heidelberg. The RICOM also had monthly online-meetings.

Topics discussed in the RICOM included preparations for the five-year plan of the third financial period, rules for updating protocols and draft versions of all documents prepared for GA or for general management.

Support for Scientific and Ethical Advisory Boards

The Scientific 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.

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 bulletin, but stresses the importance of considering a sustainable scope and frequency of such a report.

The Ethical Advisory Board prepared a draft for Ethical Guidelines, which were presented to GA in May, and processed further in a process activating the entire community with lead of the Head Office. After comments were reviewed and the report finalised and approved in November, it was published on the ICOS website https://www.icos-cp.eu/media/211.

Financial management of ICOS ERIC

The year 2022 was the third year of the second 5-year period of ICOS ERIC. During the year, ICOS launched the ERIC FORUM toolkit (as part of ERIC FORUM EU-H2020 project), and there are many documents to help ERICs to develop their administration. The Netherlands changed the responsible organisation for ICOS from NWO to TNO, and unpaid membership contributions from previous years were paid. The Academy of Finland made decision of host contributions for years 2023 and 2024. The funding became available after the requested document “Synergies with ACTRIS” was approved by the Finnish Research Infrastructure -committee. The Annual Contributions of the member countries were paid before the Autumn General Assembly meeting. Two new projects (PAUL) and (KADI) started and a decision for GEORGE funding was received. ICOS ERIC coordinates all these three projects. Greece wanted to pay the membership contribution 2023 in advance in December 2022.

Overall financial management of ICOS RI

ICOS ERIC Financial Committee had two meetings during the year. The Committee prepared reports for both meetings, however, the chair was absent from them. The General Assembly noted the increase in personnel costs compared to the previous year. In Autumn meeting, the committee noted unbalance with the budgets of some Central Facilities: the deficits will be covered by the unspent funds. The station-based contributions were divided for the first time according to the countries in every Central Facility’s budget.

Instrument register

In context of ICOS Cities project, ICOS ERIC purchased a MIRO instrument. ICOS ERIC already owns a PICARRO bought in the RINGO project. For better management of these physical assets, an Instrument register was created and will be included in the financial audits.

Human resources management for ICOS ERIC

During the year, EU administrative assistant, communication specialist and junior controller resigned. The unspent holidays have been paid with the final salaries. Two new communication officers started in March, new junior controller in May and EU administrative assistant in June. All were replacement recruitments. The call for the position of KADI project officer was opened in December 2022. ICOS ERIC salary and career path policy was finalised in May. The work was done together with a consulting company (Mandatumlife). The implementation of the policy introduced salary developments with experience and career pathways based on increased tasks and skill developments. The consequent salary increases were made in summer, and will continue based on the person's working years the Head Office. The improvements related to Work Place Survey 2021 results continued by developing the Head Office's code of conducts. A new work place survey will be done in Spring 2023 by the occupational health care company Terveystalo.

Staff rules were updated during 2022, and presented to the staff in January 2023. No comments from the staff have been received. A low-emission travel policy was created based on travel experiences. The travel policy also takes into account the employer's obligations for employee health and well-being during travel.

The following personnel was employed by ICOS ERIC during the year 2022.

- Director General (Werner Kutsch)
- Director of Carbon Portal (Alex Vermeulen), leading the Carbon Portal in Lund University. Deputy of the Director General during unforeseen absences.
- Head of Unit I 'Administration' (Anne Malm), responsible for finance, human resources and general administration.
- Head of Unit II 'Operations' (Elena Saltikoff), coordination and development of the operations of the whole ICOS research infrastructure.
- Head of Unit III 'Strategy & International Cooperation' (Emmanuel Salmon), coordination and development of the strategic and international cooperation of whole ICOS RI.
- Head of Unit IV 'Communications' (Katri Ahlgren) Responsibility for ICOS RI communication and outreach strategy, activities and ICOS brand and visual outlook.
- Science Integration Officer, Unit II (Sindu Parampil), facilitation of the initiatives of the ICOS academic community, contributing to projects and proposals, supporting the work of the ICOS Scientific Advisory Board.
- Operations Officer, Unit II (Evi-Carita Riikonen), supporting the coordination of the operations, especially the RI Committee work, supporting the planning and reporting of the RI activities, operational development tasks and project management and impact analysis tasks.
- Science Officer, Unit II (Janne-Markus Rintala), ICOS Science conference, contributing to projects and proposals especially related to ocean observations' technological and scientific research & development
- Communications Specialist, Unit IV (Mari Keski-Nisula) resigned 18.3.2022, and replaced by Maria Luhtaniemi 7.3.2022 (see later in the text).

- Executive Assistant, DG Unit (Inka Hellä), The main duties of the position include general back office and operational support for the Head Office and providing personal assistant duties for Director General.
- EU-project Administration Assistant, DG-Unit (Leysan Karimova), resigned 31.3.2022 and replaced by Emilie Hachem 1st of June 2023.
- Communications Assistant promoted to Communication Officer in August 2022, Unit IV (Karlina Ozolina), tasks and responsibilities related ICOS RI internal as well as to external communications and selected EU projects ICOS participates in (such as ENVRI-FAIR and KADI).
- Senior Officer, Data Analyst, Unit II, (Ville Kasurinen), HO contact for elaborated data products development, contributing to projects and proposals (ICOS Cities, KADI)
- Observation Network Officer, Unit II, (Maiju Tiiri), support with the coordination of the station network, ICOS Science Conference.
- Project Officer, Unit II, (Liisa Ikonen), contributes in participating and preparing for externally funded projects (ICOS Cities), stakeholder analysis.
- Communication Officer, Unit IV (Charlotta Henry), tasks and responsibilities related ICOS RI internal as well as to ICOS RI external communications activities and selected EU projects ICOS participates in (such as ICOS Cities).
- Communications Officer, Unit IV (Laurent Chmiel), communications tasks and responsibilities related ICOS RI internal as well as to ICOS RI external communications activities and selected EU projects ICOS participates in (such as ENVRI-FAIR and KADI). Since 1.3.2022.
- Communication Officer, Unit IV (Maria Luhtaniemi), communications tasks and responsibilities related ICOS RI internal as well as to ICOS RI external communications activities and selected EU projects ICOS participates in (such as ERIC Forum and RItrainPlus). Since 7.3.2022.
- Junior Controller, Unit I (Vilma Viitikko), 1.2. – 31.5.2022.
- Junior Controller; Unit I (Tommi Pesonen), travel and cost claims, assisting with the financial issues. Since 27.5.2022.
- EU administrative assistant DG-Unit (Emilie Hachem), assisting with the tasks related Horizon2020 and HorizonEurope projects. Since 1.6.2022.

12 of the employment contracts is valid indefinitely and 5 are fix-terms contract ending at the end of year 2024. During the year, four persons had reduced working time due to their own request.

Gender balance and equality

The staff consists of 7 men and 12 women, out of which 3 men and 3 women are in managerial positions. A gender equality plan (GEP), as required by European Commission in Horizon Europe projects, is published on the ICOS website. The GEP covers ICOS ERIC's processes related to general inclusivity and equality in the work place, and includes details about how ICOS ERIC monitors these processes.

Contract management

Contract on legal advisory services with the University of Helsinki ended in February. Junior controller was hired through a staffing company in January, and two persons were hired through the company to help with the tasks related to Science Conference. The Audit company was KPMG and accounting company AZETS.

Operational management of ICOS ERIC and RI (KPI 4)

The **Management plan** part 1 was published on ICOS website, and Part 2 was discussed in RICOM. Part 1 describes the general management structure and key management processes, while Part 2 in a living document with more detailed process and task descriptions and will be for the RI's internal use. Part 1 will serve as a go-to guide for existing and new staff, users and stakeholders. It also provides information about how and where to find more detailed information about specific managerial topics.

Director general, Carbon Portal Director and Head of Operations visited the Ocean Thematic Center in Bergen in May to improve the connections and to discuss the operational practises. This kind of visits have been on hold for a few years during the pandemic.

The members of Operations unit participated in the face-to-face meetings of Ocean Monitoring Station assembly (MSA) as well as the online meetings of the other two MSAs. A list of potential future funding opportunities was prepared based on leaked drafts of Horizon Europe Work programmes, and shared with the members of the MSAs.

ICOS has entered the ESFRI evaluation process, and material for the survey (deadline January 2023) has been collected. The Director general has started discussions with GA; whether the results of this evaluation can be used as the evaluation for he second 5-year period, instead of preparations of yet another evaluation in 2024.

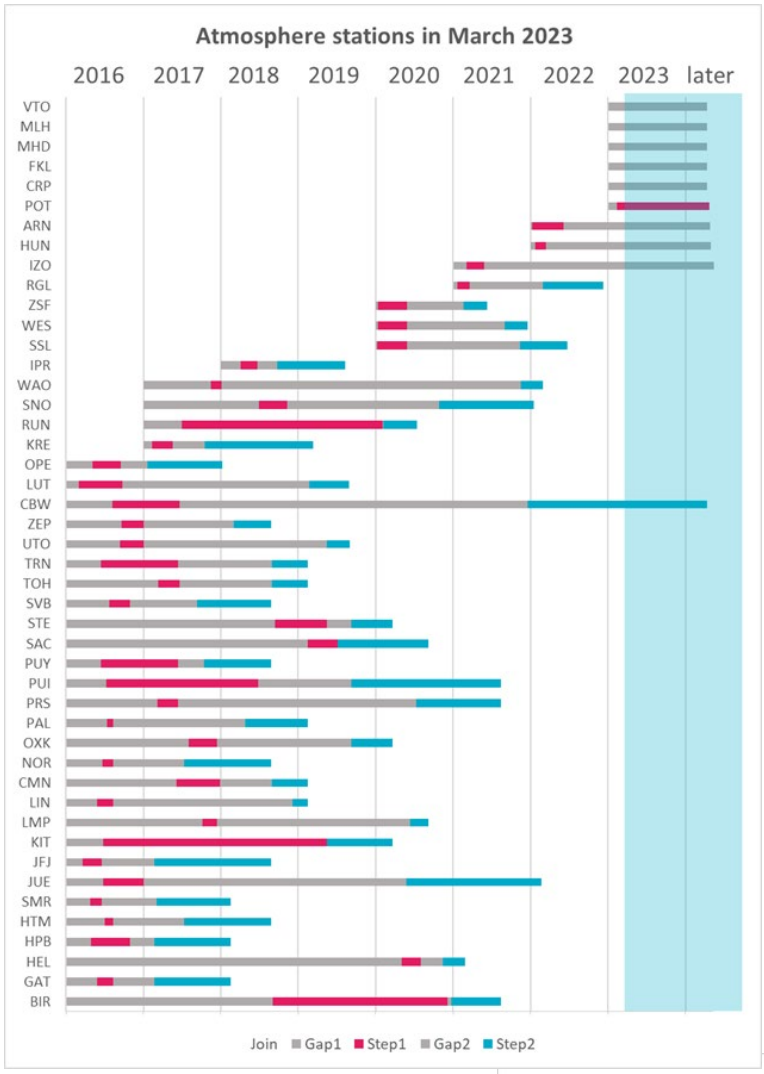
A total of 22 stations received an official ICOS label in 2022. Of these stations two were atmospheric stations, 17 were ecosystem stations and three were ocean stations. Station contracts were prepared between the ICOS ERIC and the host organisations of labelled stations. Progress of the labelling is illustrated in Table 1 and figure 1, figure 2 and figure 3.

A new graphical representation of progress of labelling was developed and introduced to GA in November (figure 1). In this graph it is easy to see, which stations have not yet been labelled because they joined later than other, which have taken long pauses in the labelling process and where the last steps have lasted for a long time. The GA stakeholders have been encouraged to be in contact with stations, where progress is slow, and where appropriate even consider removing those stations from ICOS network.

Status of the ICOS Station Labelling in March 2023

Member/ Observer countries	Stations total	Labelled stations total	Number and type of stations														% Labelled per country
			Ecosystem stations						Atmospheric stations				Ocean stations				
			C1	C1 labelled	C2	C2 labelled	Assoc.	Asso. labelled	C1	C1 labelled	C2	C2 labelled	C1	C1 labelled	C2	C2 labelled	
Belgium	11	10	1	1	4	4	2	1	0	0	1	1	3	2	0	0	91 %
Czech Rep.	4	4	1	1	1	1	1	1	1	1	0	0	0	0	0	0	100 %
Denmark	10	9	2	2	1	1	6	5	0	0	1	1	0	0	0	0	90 %
Finland	17	11	2	1	2	1	7	5	2	2	2	2	0	0	2	0	65 %
France	22	20	3	3	6	6	8	6	2	2	2	2	1	1	0	0	91 %
Germany	38	26	5	4	0	0	15	8	6	6	6	6	4	1	2	1	68 %
Greece	4	0	0	0	1	0	2	0	0	0	1	0	0	0	0	0	0 %
Hungary	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0 %
Ireland	10	0	0	0	5	0	0	0	0	0	4	0	0	0	1	0	0 %
Italy	20	13	2	1	2	2	7	4	1	0	3	3	1	1	4	2	65 %
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	5	0	0	0	0	0	1	0	0	0	2	0	2	0	0	0	0 %
Sweden	11	8	0	0	6	5	0	0	3	3	0	0	2	0	0	0	73 %
Switzerland	2	2	1	1	0	0	0	0	1	1	0	0	0	0	0	0	100 %
UK	5	3	1	1	0	0	0	0	0	0	2	2	1	0	1	0	60 %
JRC	2	2	0	0	1	1	0	0	0	0	1	1	0	0	0	0	100 %
Total	**173**	**114**	**18**	**15**	**31**	**21**	**49**	**30**	**18**	**16**	**28**	**20**	**17**	**7**	**12**	**4**	
% Labelled per domain and class:			83 %		68 %		61 %		89 %		71 %		41 %		33 %		

Table 1. Labelled ICOS stations per country, domain and class in March 2023. Note: One ocean station from Germany (DE-SOOP-Polarstern) was labelled as class 2, but has now been changed to class 1.


Atmosphere stations in March 2023
2016
2017
2018
2019
2020
2021
2022
2023
later
VTO
MLH
MHD
FKL
CRP
POT
ARN
HUN
IZO
RGL
ZSF
WES
SSL
IPR
WAO
SNO
RUN
KRE
OPE
LUT
CBW
ZEP
UTO
TRN
TOH
SVB
STE
SAC
PUY
PUI
PRS
PAL
OXK
NOR
CMN
LIN
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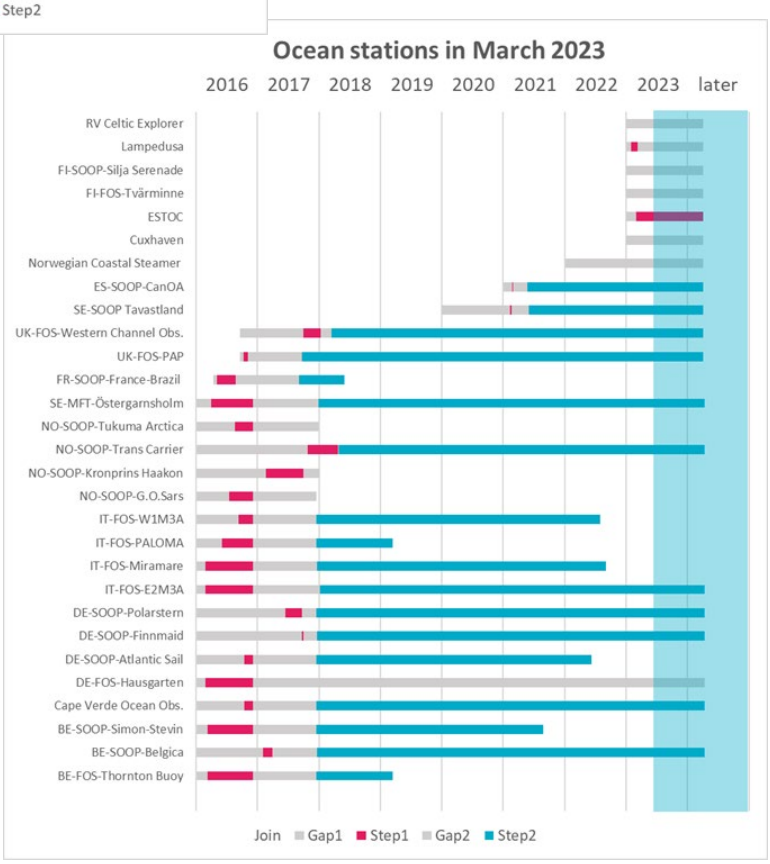
BIR
Join
Gap1
Step1
Gap2
Step2


Ocean stations in March 2023
2016
2017
2018
2019
2020
2021
2022
2023
later
RV Celtic Explorer
Lampedusa
FI-SOOP-Silja Serenade
FI-FOS-Tvärminne
ESTOC
Cuxhaven
Norwegian Coastal Steamer
ES-SOOP-CanOA
SE-SOOP Tavastland
UK-FOS-Western Channel Obs.
UK-FOS-PAP
FR-SOOP-France-Brazil
SE-MFT-Östergarnsholm
NO-SOOP-Tukuma Arctica
NO-SOOP-Trans Carrier
NO-SOOP-Kronprins Haakon
NO-SOOP-G.O.Sars
IT-FOS-W1M3A
IT-FOS-PALOMA
IT-FOS-Miramare
IT-FOS-E2M3A
DE-SOOP-Polarstern
DE-SOOP-Finnmaid
DE-SOOP-Atlantic Sail
DE-FOS-Hausgarten
Cape Verde Ocean Obs.
BE-SOOP-Simon-Stevin
BE-SOOP-Belgica
BE-FOS-Thornton Buoy
Join
Gap1
Step1
Gap2
Step2

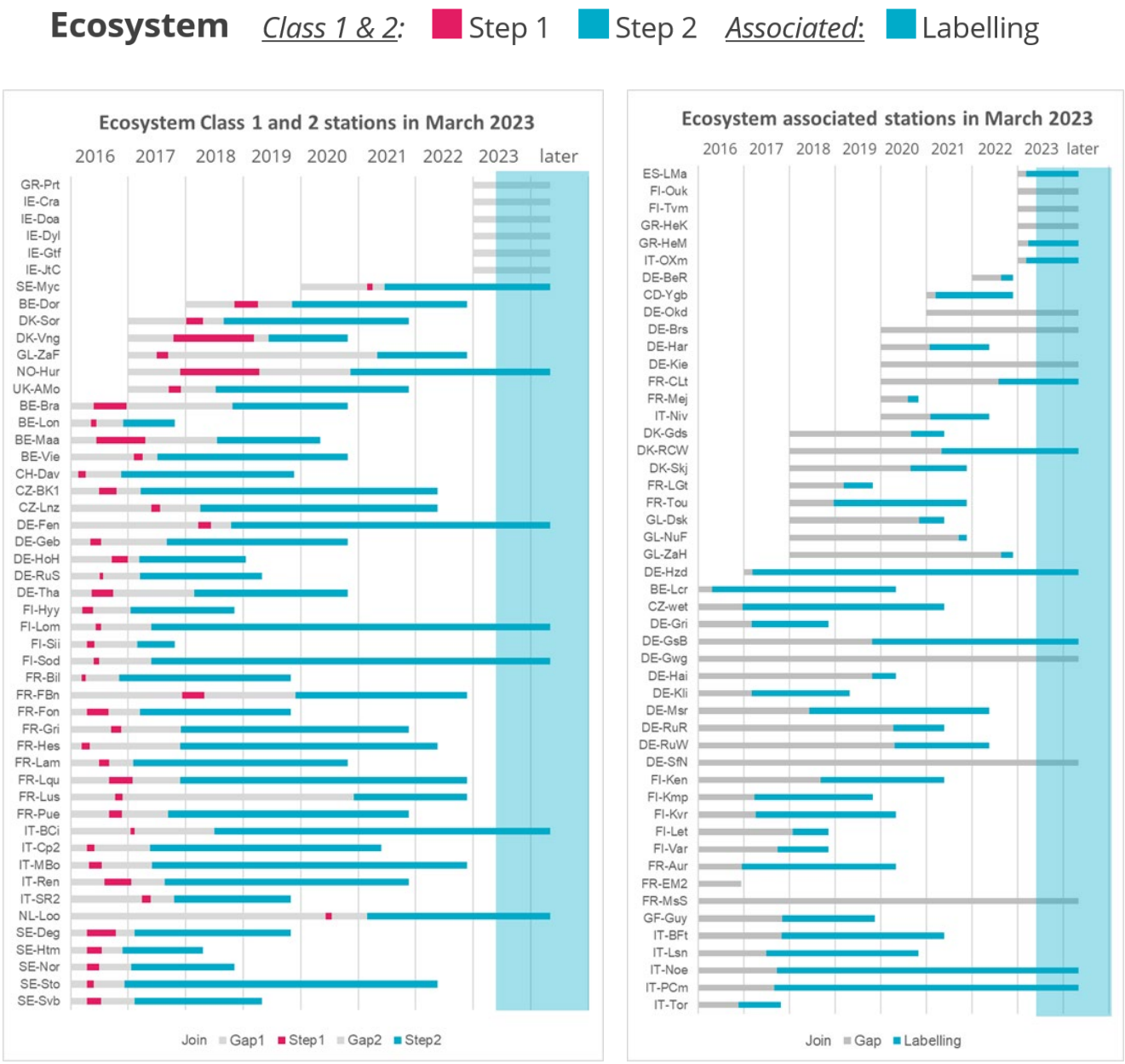


Figure 2-3. Progress of station labelling in each domain in March 2023.

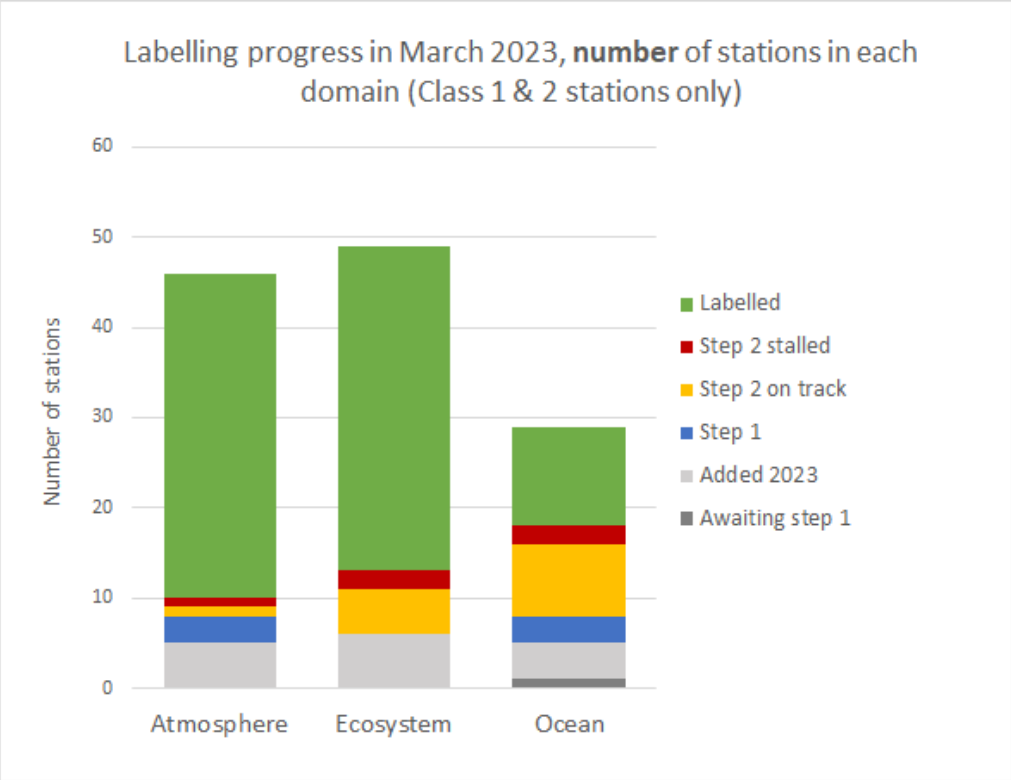


Figure 4. Labelling process, per cent of stations (Class 1 and class 2) in each labelling step by domain.

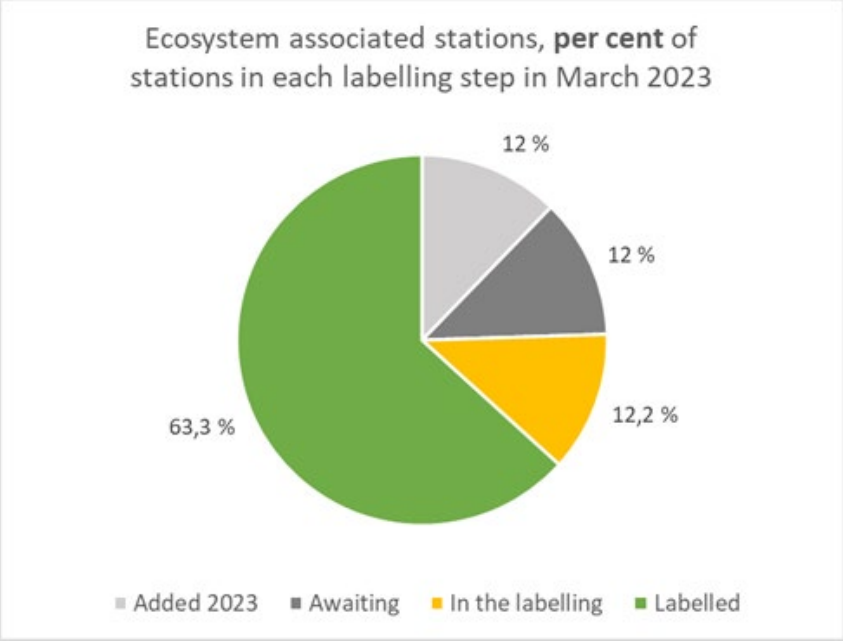


Figure 5. Labelling process of associated ecosystem stations in March 2023.

The station level progress of labelling can be followed from https://meta.icos-cp.eu/labeling/
As advised by the SAB, we suggest a new KPI: number of stations in status " delayed" (yellow) or "stalled" (red), and the % of "stalled" stations which have been contacted by the TC within the last year.

Currently, 11 stations are "Step 2 delayed" and 6 stations are in status "stalled".

Stations, where labelling was stalled as of 26 April 2023

Domain	Station		Notes
ECO	Fendt	DE	No real activities in the labelling process, ETC is waiting metadata and data (Step1 approved 2018-08-06 and Step2 started 2018-10-17). Nothing happened until November 2022
ECO	Grosses Bruch	DE	Associate station. Completed first step Dec. 2019. No data or metadata submitted.
ECO	Hetzdorf	DE	Associate station. Completed first step April. 2017. No data or metadata submitted. Staff communicated problems with the personnel available due to two members not more in the team, they informed the FP.
ECO	Lompolojänkkä	FI	No data submission started. Step1 approved 2016-08-28 and Step2 started 2017-05-29
OCE	R/V Belgica	BE	The new R/V Belgica is operational from January 2022. pCO2 data is available and will be submitted early 2023
OCE	Western Channel Observatory	UK	No response from PI, but from the web site, it seems that the station is active.

Support for ICOS-related science

The main activity for science facilitation was Science conference 2022 (see highlights).

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 https://doi.org/10.18160/2G60-ZHAK for more information

Marie Skłodowska-Curie Action (MSCA) Doctoral Network (DN) training proposal (CarboAdvance), coordinated by Ivan Mammarella of ICOS Finland and supported by HO, was submitted in October 2022. CarboAdvance was scored highly but unfortunately not funded when the results were announced in April 2022. Based on the comments and critiques from the reviewers, the consortium reworked the proposal and re-submitted (as one of 900 proposals) and results are expected in April 2023. 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 CarboAdvance is training the next generation of greenhouse gas scientists while 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 PIs can learn from the strategies and successes in other National Networks. This would potentially, open opportunities for future collaborations on EU calls and proposals. In addition, the SFP document, which will be an addition to the Management Plan, Part 2, aims to summarise and document the various means by which HO supports ICOS scientists and their science. The document is to be tentatively completed by the end of 2023.

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.

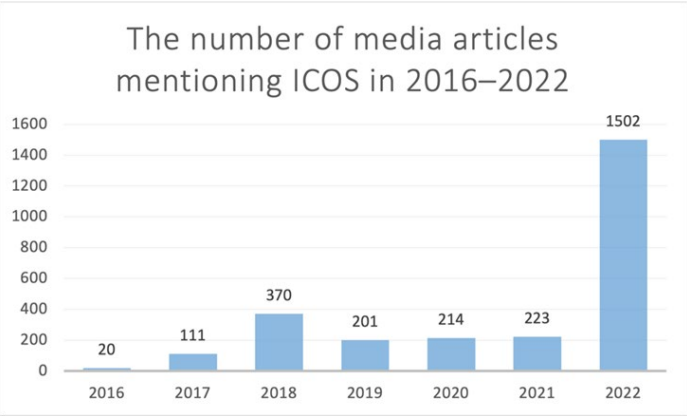
FLUXES, the European Greenhouse Gas Bulletin is a new publication by ICOS, which aims at highlighting climate issues to an audience of policymakers, policy advisors, and climate journalists.

The first volume of FLUXES which was prepared 2022, focused on regional and year-over-year changes in carbon sinks in Europe. These changing sinks highlight the need to reduce emissions further in order to reach carbon neutrality targets. (See more in highlights)

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.

Visibility of ICOS in media skyrocketed during the NordStream methane leak, which was detected at ICOS stations around the Baltic Sea. (See more in highlights)



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.

Figure 6: ICOS mentions in global online media 2016-2022.

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 at 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

The addition of two new member countries to ICOS ERIC was completed under 2022: as of 1st January 2023, Greece and Ireland joined ICOS, allowing for a significant geographical extension of the network both to the North-West and South-East of the continent. This will allow for a denser and even more scientifically relevant observation network in ICOS. The addition of 14 new stations (10 in Ireland and 4 in Greece) represents an increase of almost 10 % of the total network.

In 2022, Switzerland also engaged nationally in a legislative process in order to upgrade its membership in ICOS ERIC from an observer status to a full membership. This will further strengthen the role of Switzerland, a major scientific contributor to the ICOS community.

While discussions are being held with a number of interested countries on a regular basis, the HO will intensify in the future its activities towards candidate countries that would contribute to further improvements of the ICOS network. This is in particular the case of Poland and Portugal that would expand the geographical coverage along the South-West—North-East axis in Europe.

In 2022, international cooperation outside of Europe saw developments especially in two areas. In September, the new Horizon Europe "Knowledge and Services from an African Observation and Data Infrastructure" (KADI) project started officially. It was kicked-off in October in Johannesburg with representatives of the European and African partners (in Côte d'Ivoire, Kenya, South Africa and Tanzania). The project will advance the concept of an African Research Infrastructure for the observation of greenhouse gases that was initiated by the SEACRIFOG project (2017–2020).

The Global Ecosystem Research Infrastructure (GERI), a consortium between ICOS and 5 other world-class RIs in Africa, Australia, China, Europe and the US, saw significant steps in 2022. It was presented at the biennial International Conference on Research Infrastructures (ICRI) in Brno in October, equally prominently in the main program as in the side- and satellite-events. A visual identity was created and a website was established (www.global-ecosystem-ri.org) that will be gradually populated by the partners.

After the disruptions caused by the global pandemic in the last years, the major international forums resumed their activities in person. ICOS ERIC was present at the Conference of Parties to the United Nations Framework Convention on Climate Change (COP27) in Sharm el-Sheikh (Egypt) in November. As an observer to the Convention, ICOS organized, in partnership with the state of Côte d'Ivoire and the NGO Climate Chance, a side-event entitled "Systematic observation of greenhouse gases (GHG) to support climate action in cities and regions". A poster at the Earth Info Day and various contributions of the DG and other members of the ICOS community at side-events organized by the European Union,

the World Meteorological Organization... were also provided. The same is also valid for the June meeting of the Subsidiary Body on Scientific and Technological Advice (SBSTA) to the Convention.

Green Team

The Green Team, that was established in ICOS ERIC HO before the COVID in 2019 was reactiveted in 2022 after the COVID-related travel limitations. This team continues to build self-awareness via monitoring of HO personnels business travelling and daily work-home-work commuting. This practice has succeeded to decrease our emissions significantly (fig. X)

Travelling decreased significantly during the COVID regulations, but increase again during 2022. COVID helped to mitigate climate change in two ways, it forced the society to improve remote participation tools and made people adopted to use these new tools. Therefore business travelling is not always necessary and this in combination with the newly implied slow travelling has enabled ICOS ERIC HO in decreasing it's carbon emissions caused by travelling. As pilot studies, one staff member travelled to EGU in Austria, and one to ICOS Science Conference in Netherlands without flying. Therefore these new slow travelling methods for travelling were allowed depending on the work load an remote work possibilities during the travelling, albeit of not making it mandatory.

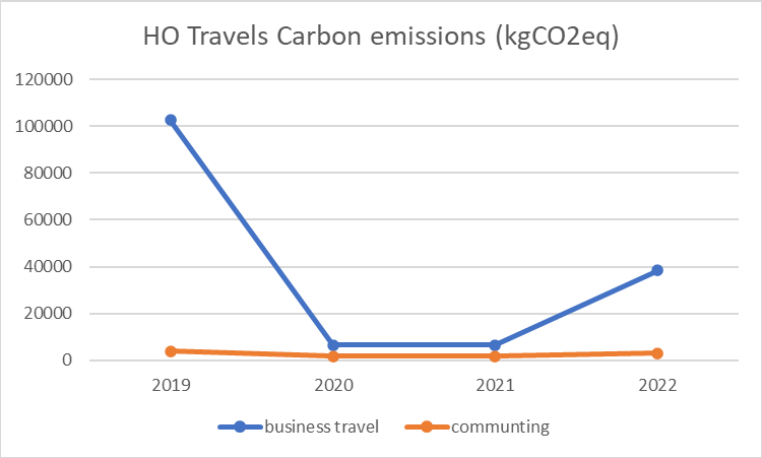


Figure 7. CO_2 emissions of HO travel decreased sharply due to Covid-19.

Carbon Portal

General

Mid 2022, after the COVID pandemic started to loosen its grip on society, 2022 became almost a normal year. However not without changing the way we work in many ways. Most obvious is the increased amount of working from home and the continued increased amount of online meetings, only partly to replace in person meetings, causing less travel but also fuller agendas. The year 2022 was also the year in which all ICOS data streams are now fully operational and more and more stations have become labelled, leading to them sending more and more data. This has lead to significant higher pressure on the operational side of business and leaving less room for innovation and development. Also the amount of users and their data use is increasing, together with the amount of data. To keep all services up and running and up to date is now taking most of the effort in the core infrastructure work at Carbon Portal. Nevertheless the availability of the CP services in 2022 was better than 99.7%. This was lower than 100% because of a forced move of the CP servers to another rack due to a restructuring of the LUNARC server room and an unfortunate power off by mistake. Improved resilience of the core services is now one of the targets for 2023.

Data Statistics

Data availability

In 2022 CP received in total 339 703 data objects, of which 339 188 are considered ICOS data. Of these 176 649 came from the atmosphere, 159 728 from the ecosystem and 2 742 from the ocean domain. 69 ICOS data objects were of the mixed data theme, mainly model and emission data results. In total 80 mixed data theme data objects were received as non-ICOS data. The big share of ICOS data is raw data (L0, 188 669), but also the daily growing NRT data files (L1, 148 397) form a considerable part of the total number of files. A total of 776 data objects were received as Level 2, final quality controlled, ICOS data. At the end of 2022, the Carbon Portal held in total more than 1.1 million data objects.

Figure 1 Statistics on number of data objects received in 2022

Total		**339 703**
ICOS data objects		339 188
	Atmosphere	176 649
	Ecosystem	159 728
	Ocean	2 742
	Mixed theme	69
	L0	188 669
	L1	148 397
	L2	776
Other data objects		565

Figure 1 and 2 show the percentage per month of raw data received for the individual stations of the ecosystem and atmosphere domain respectively. Clearly one can see that the number of stations sending data increases because of the growing number of labelled stations. For all years and over the whole period all stations show a data availability of more than 95%. Table 1 summarises the data per year and over the whole period for the two networks. No significant upward or downward trend can be seen over the period 2020-2022 which means the overall network behaves consistently and reliably.

Table 2 Percentage of raw data received for the domains of atmosphere and ecosystem for the years 2020, 2021 and 2022, and for the whole period 2020-2022

	Year	2020	2021	2022	2020-2022
Atmosphere	**AVERAGE**	95,7%	96,6%	96,3%	96,2%
	MEDIAN	96,1%	96,6%	97,0%	96,6%
Ecosystem	**AVERAGE**	98,3%	98,2%	97,9%	98,1%
	MEDIAN	99,7%	99,6%	99,4%	99,5%

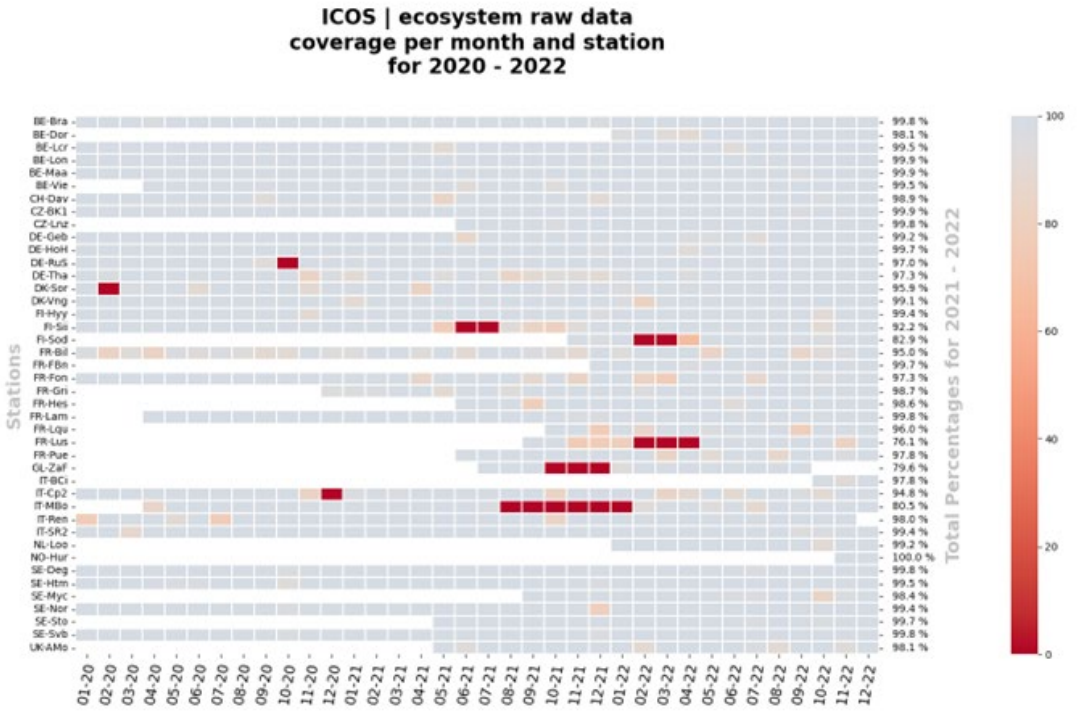


Figure 1 Percentage of raw data coverage over the month received per ecosystem station for 2020-2022

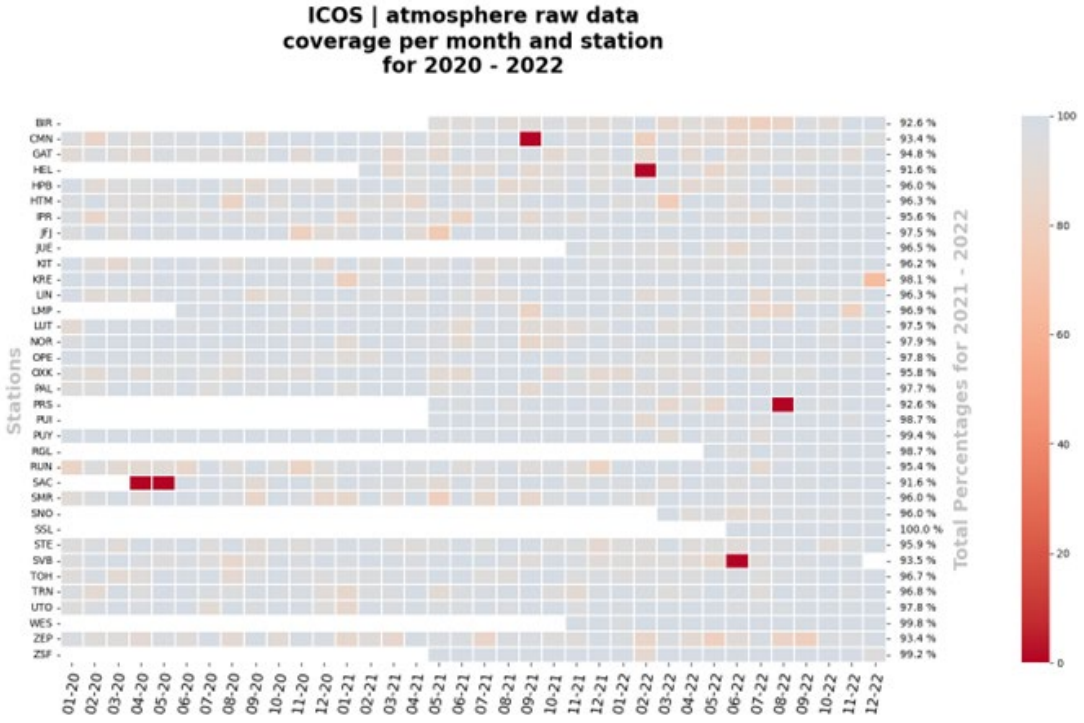


Figure 2 Percentage of raw data coverage over the month received per atmosphere station for 2020-2022

Data releases

All domains delivered at least one release of level 2 final quality data. Ocean 17 January, Ecosystem 14 June and Atmosphere 13 July. In addition, additional L2 dataset of Ecosystem data until the end of growing season was released in December 2022-January 2023.

Obspack data product was prepared and released in March 2023.

Data usage by download count and user number

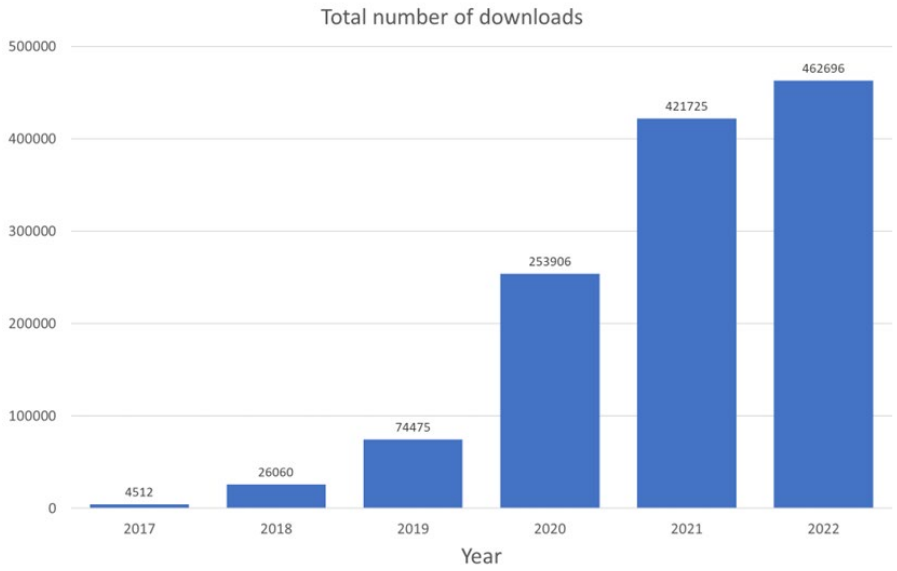


Figure 3. Total number of data downloads from Carbon Portal from 2017 to 2022. In 2022 the number of downloads of ICOS Level 1 and 2 data: 290 000

Another statistic relevant to the use of ICOS data is the number of data use through the apps of Carbon Portal, for example the data preview, the Dashboard and the python library. Total number of access per month is shown in figure 4.

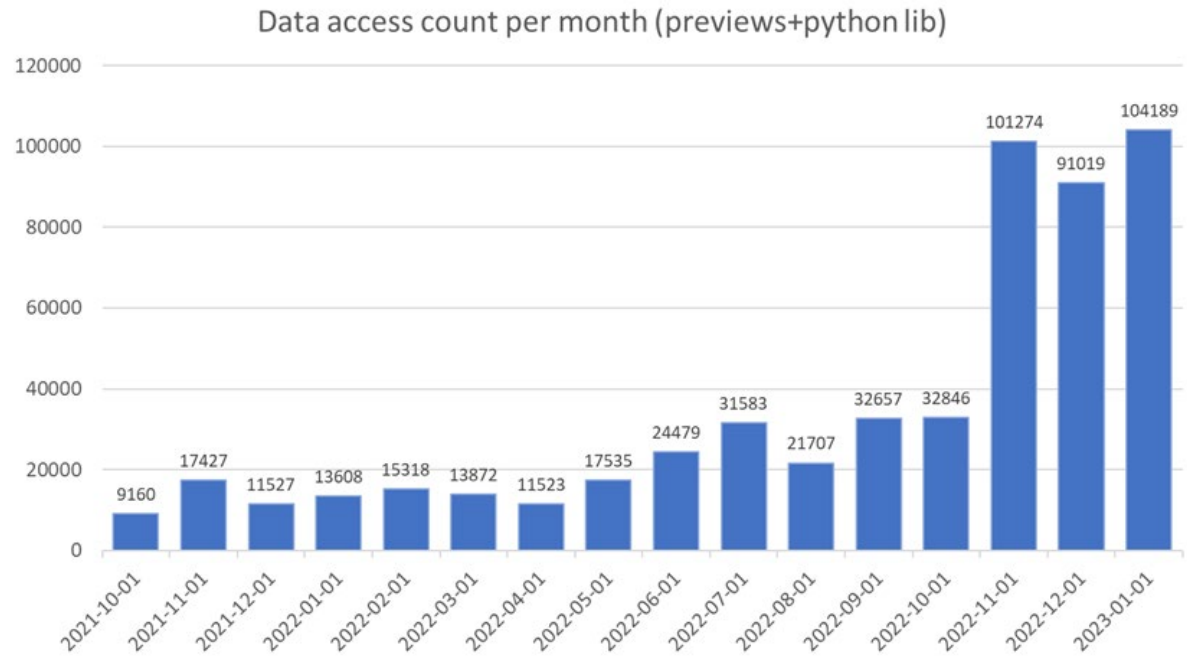


Figure 4. Number of access of ICOS data other than through direct download through the portal

We can further zoom in on specific data uses and for example for the number of timeseries previews we can clearly identify a spike in interest corresponding with time of the Nordstream I+II methane leaks that were detected in the ICOS network, which caused a lot of interest for a prolonged period (Figure 5).

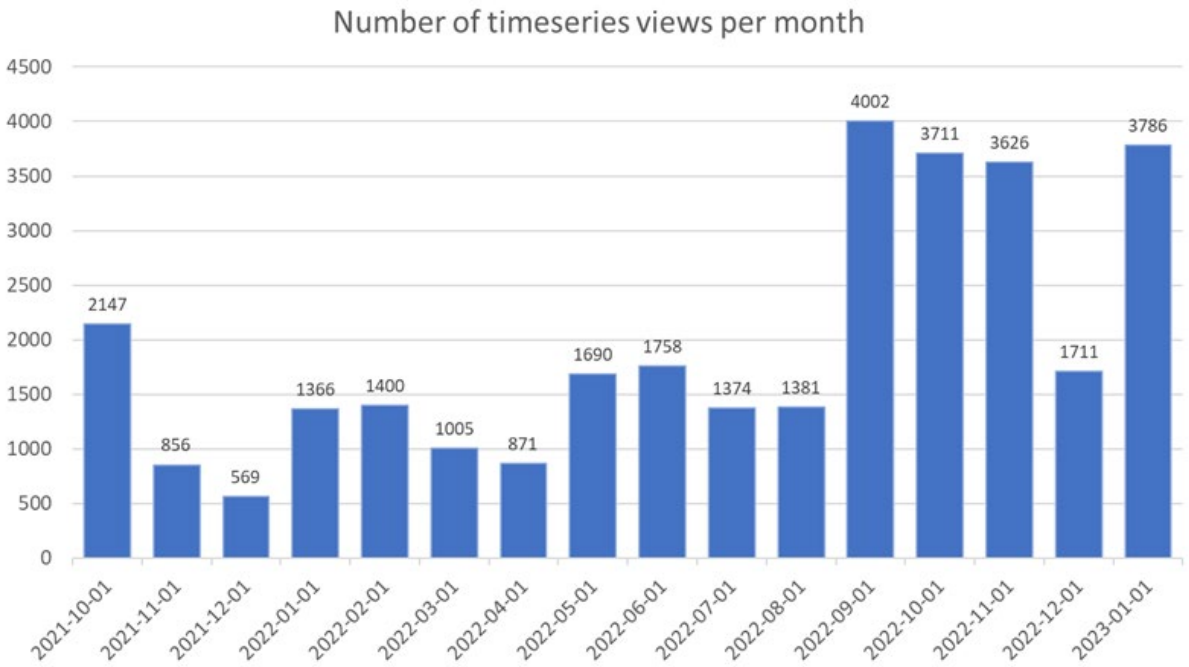


Figure 5. Number of timeseries previews at Carbon Portal during the reporting period

Total amount of unique users of web pages and web services

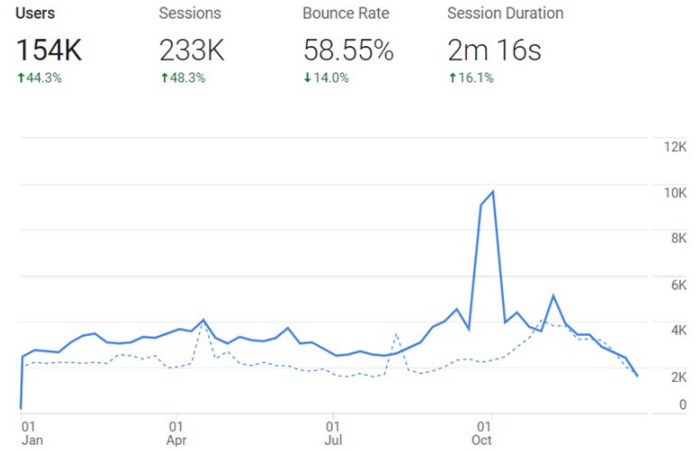


Figure 6 Number of unique users per day of the ICOS web site plus Carbon Portal. Clearly a peak of interest can be identified around the Nord Stream methane leakage event. The total numbers of unique users over 2022 was over 154000 users.

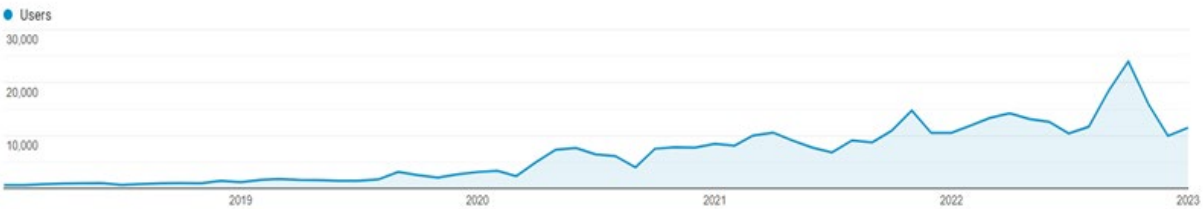


Figure 7 Number of unique users per month in the period Jan 2018 until Jan 2023, showing a clear trend towards on average 10000 users per month in early 2023.

Impact

Impact through articles and citations

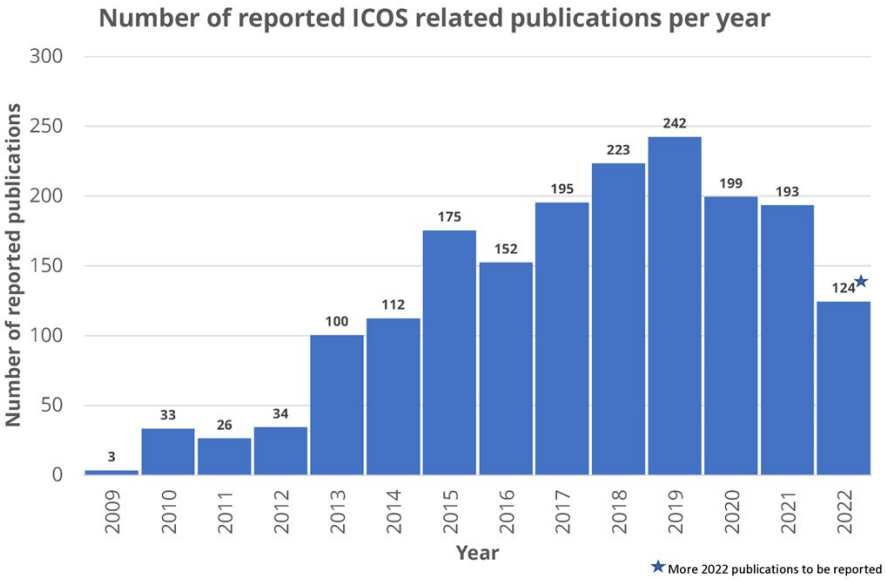


*Figure 8 Number of ICOS related **publications** per year (reported)*

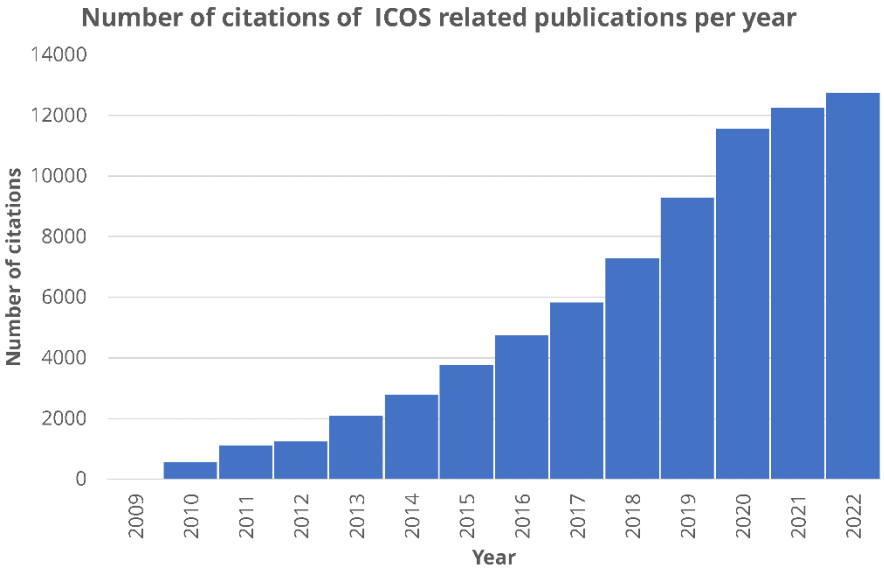


*Figure 9. Number of **citations** of ICOS related publications per year*

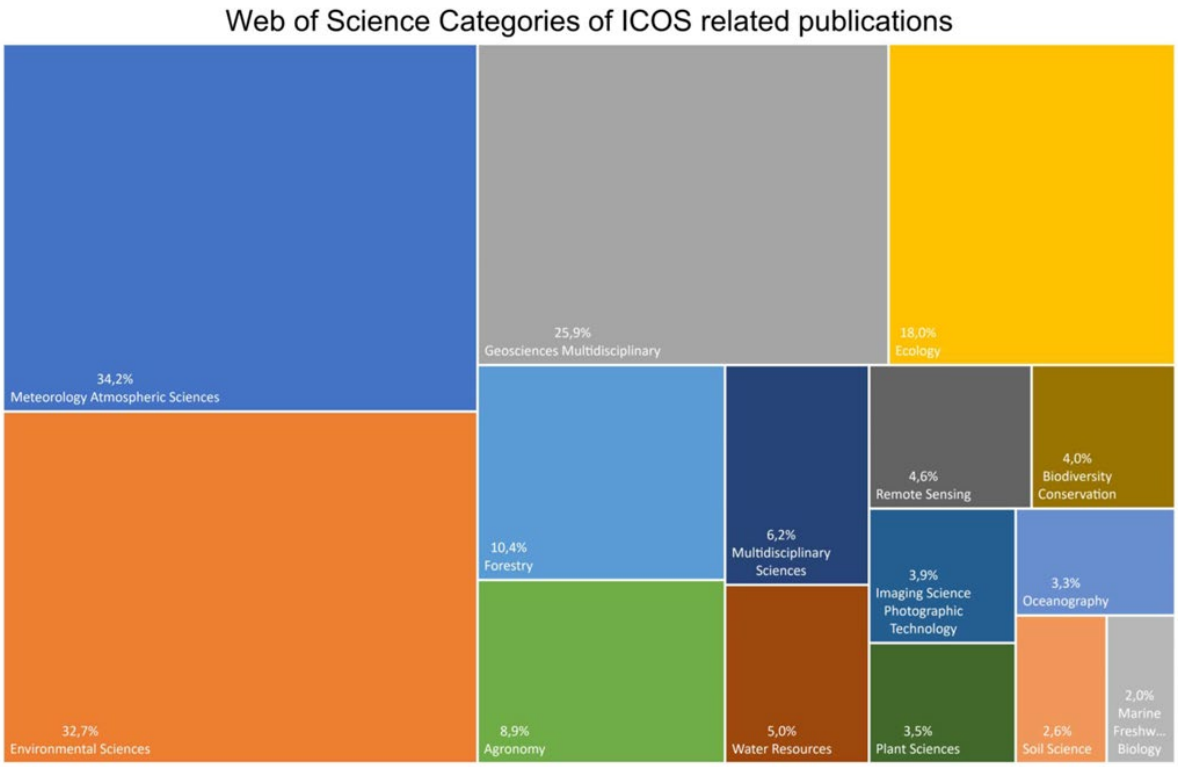
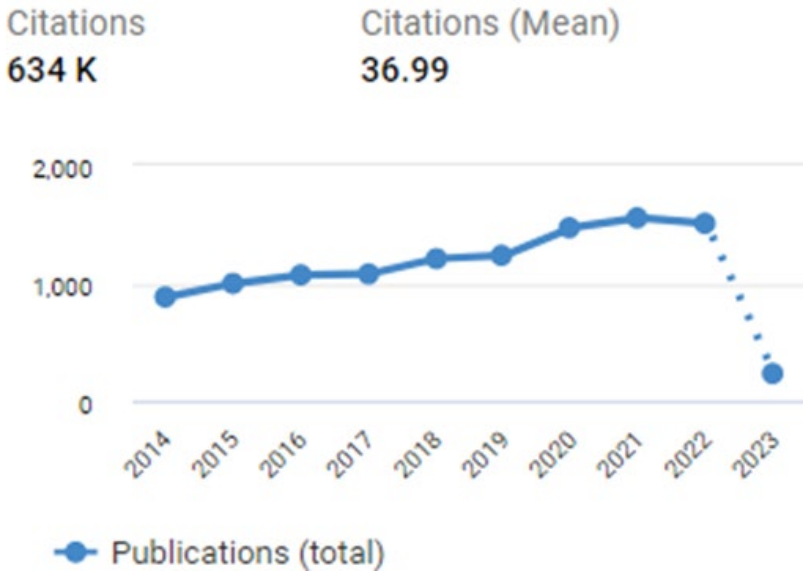


Figure 10. Categories of ICOS publications in 2022. The six largest categories of ICOS publications were Meteorology Atmospheric Sciences, Environmental Sciences, Geosciences Multidisciplinary, Ecology, Forestry and Agronomy.

Impact through citations of data and referring articles

508 datasets, 17 132 publications, about 1500 per year



Elaborated products

Jupyter notebooks

The Jupyter Notebook services at CP have seen an increasing number of users in 2022, both in the collaborative Jupyter Hub, with currently 160 registered users, and in the semi-public service exploredata.icos-cp.eu. The collaborative Jupyter Hub with its advanced options like sharing notebooks and data between users of collaborative projects and with associated disk space on the ICOS Fileshare allows users to upload own data for analysis together with ICOS data, and provides permanent storage of notebooks and data. The services are regularly updated to provide users with a versatile python (also R, Julia) programming environment and are continuously expanded in close consultation with our users to support their scientific analysis and interpretation of ICOS data and products.

The ICOS-specific python library for easy access to the ICOS data and metadata that is available in the Jupyter Notebook services, as well as for installation on local computers, has also been continuously improved and expanded to reflect the developments in the data portal.

Jupyter notebooks for the characterization of ICOS atmosphere stations and analysis of the monitoring potential of the current ICOS atmosphere network and its planned expansion were developed based on results from the STILT footprint tool and are available for all interested users on the Jupyter Notebook services. Footprint tool results and their further analysis in Jupyter notebooks have again supported several studies resulting in scientific publications and presentations.

New and updated data products

We introduced the CarbonTracker Europe High-Resolution (CTE-HR) system, a comprehensive tool that provides near real-time and up-to-date estimates of CO2 exchange over Europe.The CTE-HR system offers high-resolution (0.1°×0.2°) and dynamic anthropogenic emission model, which leverages open-access statistics on economic activity, energy use, and weather to generate anthropogenic emissions at high spatial and temporal resolution (0.1°×0.2°, hourly). The system's estimated net ecosystem productivity (NEP) is calculated by SiB4, driven by meteorology from ERA5, and is downscaled based on high-resolution land-use data. NEP is combined with the Global Fire Assimilation System (GFAS) fire emissions to create terrestrial carbon fluxes. Oceanic carbon fluxes are included as well, these are based on the CarboScope inversion, extrapolated based on sea surface temperature and wind speed (from ERA5) and dynamic anthropogenic emission model, which leverages open-access statistics on economic activity, energy use, and weather to generate anthropogenic emissions at high spatial and temporal resolution (0.1°×0.2°, hourly).

The products for use in atmospheric transport models and inversions, which are already regularly made available at CP, have continued to be updated. These include regional biosphere model results (VPRM and LPJ-GUESS), anthropogenic CO_2 emissions and radon exhalation from soils, all with high spatial and temporal resolution.

STILT modelled footprints and CO_2 concentrations time series for all atmospheric ICOS stations are now also available to users for direct download.

Upload and curation of these elaborated products, possibly including DOI minting, is handled by CP personnel in close contact with product providers. Development of an automated workflow for recurring datasets is underway. However, the diverse content of these products still requires specific solutions.

Data portal

The lists of improvements are provided in a roughly chronological order.

Improvements in functions and usability

- Filter inversion added to the portal app GUI.
- Harmonization of code for the station maps on the website and in the portal app.
- The basic/default data object landing pages have been integrated into the portal app (instead of using an in-app view duplicating the functionality).
- Support for data object moratorium: a possibility of upload with specified moratorium date in the future. The object is findable, but cannot be downloaded until the moratorium date.
- Updating the visual webpage style to make it uniform across the Drupal ICOS website and the in-house services.
- Improvements of the documentation for new developers setting up development environment.
- Various robustness improvements in the ETC logger facade for data uploads.
- Updating all Scala code from Scala 2 to Scala 3 (a major update).
- RDF database (RDF4J) updated to the latest version (directly from 2.x to 4.x).
- Downtime during restart of meta service has been reduced from 100 seconds to well under 10 seconds, DOI citations cache made persistent during restart.
- Better architecture documentation (e.g. Architecture info in the infrastructure GitHub project wiki, and the Mermaid service communication diagram in the project readme). See also https://doi.org/11676/cpFundamentals and links therein.
- Cleanup of duplicate (pre-ICOS vs newly-ICOS) station metadata entities.
- DOI citation cache invalidation from the doi app when editing DOI metadata.
- Added integration tests for a suite of SPARQL queries used in various services by various users.
- Consistency and performance improvements in the map view in the portal app.
- Improvements of the PID search feature in the portal app.
- Collaborations with the Elaborated products team to improve the icoscp Python library.
- DOI app improvements (support for funding information, geo- and temporal coverage)
- Overhaul of the time series preview GUI in the portal app.
- More consistent single/multiple data object download functionality in the portal app.
- MongoDb database (used for user profiles and CP service usage info) updated to a much newer version (from 3.x to 5.x).
- Better metadata for draft DataCite DOI creation from the UploadGUI app.
- Tighter metadata validations during data/document object uploads. Fine-grained control over same-filename uploads (forbid without deprecation by default, allow autodeprecation).
- Enabled more servers for STILT calculations.
- Validating all ZIP files during upload (checking that they are actually zip files).
- Work on enriched landing paged for ICOS stations (enhanced with extra multimedia content) has been mostly completed by CP on request from HO. Pending feedback/content from HO as of 2023-03-01.
- General numerous bugfixes and small issues.

FAIRness improvements

- ICOS/CP ontology has been prepared for linking value types to external vocabularies based on SKOS. Mapping to NERC P01 vocabulary has been used as a pilot application.
- Support for data license metadata implemented in RDF, JSON and schema.org's json-ld. For now, only the standard ICOS and SITES licenses, as well as the CC0 license, are fully supported, but basic provisions have already been made for more license types and multiple licenses.
- Data object metadata has been made available in ISO19115-3:2016 XML format.

- Enhancements to CP's DCAT metadata export: added metadata about stations and variables for ENVRIFAIR WP11 Site Documentation Interoperability Use Case.

F.A.I.R. is a fairly recently minted concept (Wilkinson et al., 2016; see also https://www.go-fair.org/fair-principles/fairification-process/), that has been formulated as principles, without making reference to specific implementations, although it is stated that using the approach (as applied in Carbon Portal) of using Linked Open Data (LOD) and semantic web technology comes quite natural to build FAIR data systems. Measuring compliance to the FAIR principles is straightforward, as the concept is purposely defined loosely , but there is a clear need to be able to track progress and compare different systems on the way to achieving FAIRer data systems. In the framework of the GoFAIR project work has started to use so called FAIR Implementation Profiles (FIP) to document better the choices repositories and communities have made to achieve their FAIR(er) data systems. In ENVRI-FAIR (See chapter 9) the Environmental RIs have worked together with GoFAIR as one of the pioneering communities to test out and co-develop the FIP framework. For what it is worth, in 2022 from all participating repositories and communities the Carbon Portal scored highest in number of implemented elements of the profile and showed high cross-domain convergence with other RIs.

Another way of 'scoring' FAIRness has been developed by the FAIRsFAIR project (https://www.fairsfair.eu/) using the F-UJI tool (https://www.f-uji.net/), that provides a numerical score from 0 to 100% on how FAIR a certain data set is provided, the score is based on the FAIRsFAIR Data Object Assessment Metrics. In Figure 8 the F-UJI score is shown for an ICOS Level 2 data object. The resulting score is 79%, which is graded as Advanced level. In a study performed by the European Commission (2022), ICOS Carbon Portal ranked 8th on the 26 tested repositories (see Figure 9). This result was achieved in 2020 with a score of 65%, now CP would rank 3rd or 4th with the score of 79%.

	Score earned:	Fair level:
Findable:	6 of 7	advanced
Accessible:	2 of 3	moderate
Interoperable:	4 of 4	advanced
Reusable:	7 of 10	moderate

Figure 11 F-UJI score for the FAIRness score of an ICOS Level 2 data product et at the end 2022

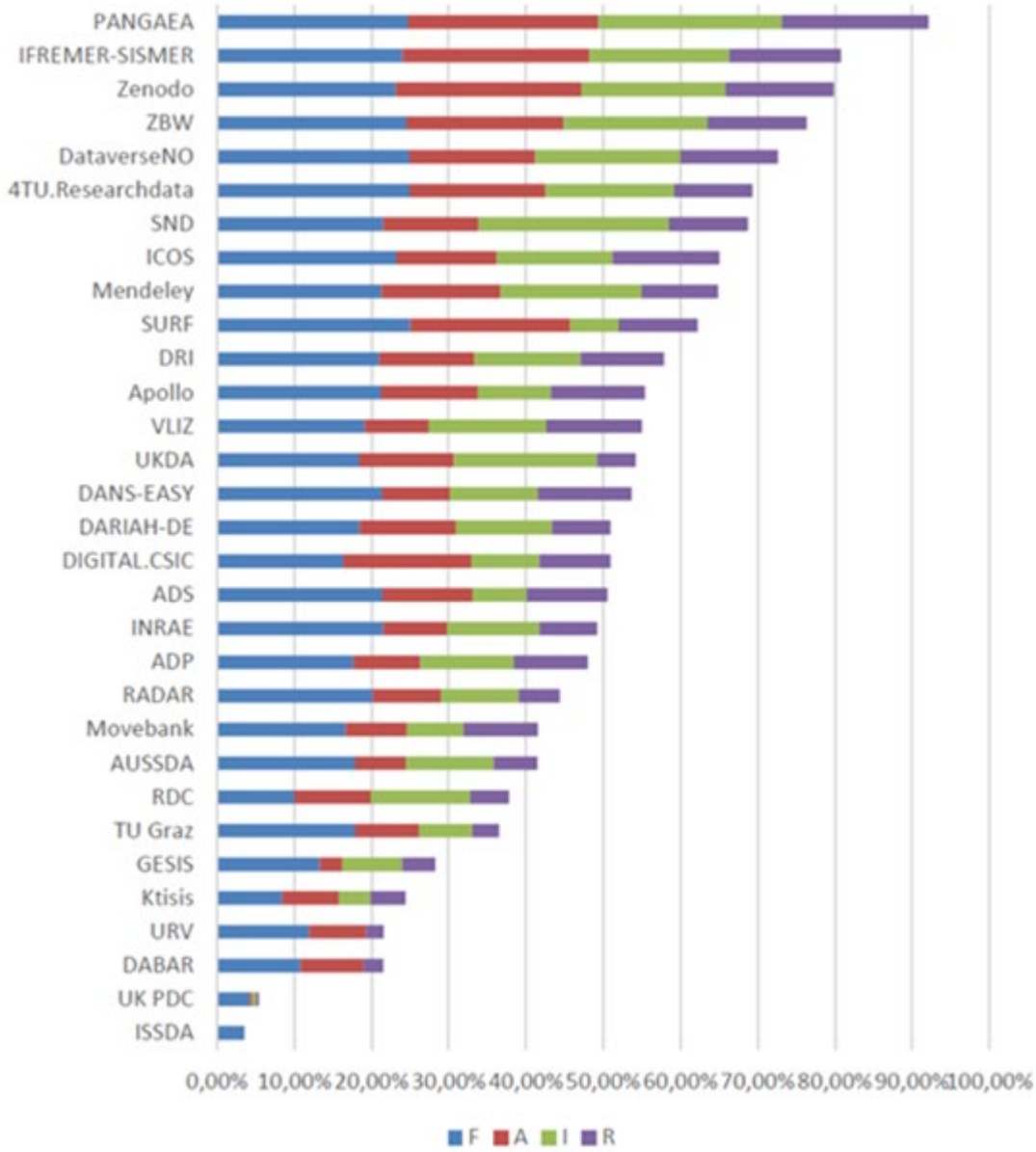


Figure 12 Comparison of the FAIRness scores of 31 data repositories using the F-UJI tool according to European Commission (2022), the comparison was performed in 2020.

New and updated data services

- Regular uploads of ecosystem L1 data supported (and happening).
- Warm Winter 2020 datasets published.
- STILT web app has been updated and improved.
- Data upload GUI has got support for GCMD keywords, to be associated with data objects during upload.
- Custom SPARQL caching mechanism implemented in the meta service, as NGINX cache mechanism has proved to be inadequate for the purpose.
- The history feature of the station labelling app has been improved.
- Greater metadata flexibility to support STILT results upload: pre-viewable L3 data can now also be station-specific time series (not only spatio-temporal NetCDF files). Conversely, spatio-temporal datasets are now optionally associated with stations.
- More performant ingestion of STILT results data has been implemented. The data is now available at CP.
- LPJ-GUESS output datasets have been accommodated for and uploaded to CP.

- Staging environment for the core authentication/data/metadata services has been configured, enabling test deployments prior to deployments to production.
- Metadata entities for organizations and persons got custom-made landing pages.
- Atmospheric L2 data release.
- "European pre-Obspack" data release preparations, upload support and post-upload metadata rectification.
- Support for FOS (fixed ocean station) data, first examples now available at CP.
- Support for phenocam image uploads added to the ETC-specific logger facade, the data is available at CP.
- Support for one-dimensional time-series data in NetCDF format (in addition to the various flavours of ASCII/CSV). Included overhaul of most of the NetCDF-specific code, and porting the Java parts to Scala 3.
- Diverse and extensive Drupal web development work for various projects (ICOS, ICOS CITIES, ACTRIS, etc)

CoreTrustSeal certification

The CoreTrustSeal certification, supported by the FAIRsFAIR project, has been a slow process, due to delays partly caused by the COVID periods and slow response by both Carbon Portal and the reviewers. We submitted the final version (after receiving the initial review by the reviewers) early 2022 and received the result end of 2022. Unfortunately the reviewers would like to see some improvements still in the application, especially with regards to a formal written and approved contingency plan in case the Carbon Portal would cease to exist. We plan to submit again in the first half of 2023 with a slightly more positive (or less self-critical) self-assessment.

Data science

Through the engagement of Carbon Portal staff, ICOS is involved in various initiatives that seek to develop research data management (RDM) concepts and associated technologies that can support and sustain Open Science and FAIRness – both for human and "machines". In part this work is carried out in the framework of European research and infrastructure development projects, like ENVRI-FAIR and EOSC Future, where the CP has contributed to discussions and scientific use cases that both identify gaps in understanding and interoperability, and then develop technological solutions to these issues. Of special interest has been investigating how ICOS can streamline the use of persistent identifiers (PIDs)

In parallel to these efforts, ICOS is also represented in working and interest groups of international initiatives like the Research Data Alliance (RDA)[1], the FAIR Digital Object Forum and others, as well as the EOSC Association's Task Force on Persistent Identifier Policy and Implementation. In these fora, we have contributed to discussions and other activities (surveys, recommendations) with insights from a "research infrastructure as end user" perspective.

RDA:

- FAIR DO Fabric IG[2]: M. Hellström (appointed co-chair in August 2022) is a contributing member, coordinating activities on FDO-related training and awareness-raising.
- InteroperAble Descriptions of Observable Property Terminology (I-ADOPT) WG[3]:

[1] Research Data Alliance (RDA),https://rd-alliance.org/

[2] RDA FAIR Digital Object Fabric IG, https://www.rd-alliance.org/group/FAIR-digital-object-fabric-ig.html

[3] RDA I-ADOPT WG, https://www.rd-alliance.org/groups/interoperable-descriptions-observable-property-terminology-wg-i-adopt-wg

- Education and Training on Handling of Research Data IG: contributions to the development of the specification on a minimal metadata set for learning resources, as well as the development (in progress) of DCAT application profiles for learning resource metadata.

FDO Forum: M. Hellström is a contributing member of the working groups on Technical Specification & Implementation (TSIG) and Basic Infrastructure and has in this role co-authored several reports, including the FAIR DO Specifications draft.

Training on Open Science, RDM and FAIR

ICOS Carbon Portal is actively engaged in developing and delivering training based on ICOS services, knowledge and experiences.

- ENVRI-FAIR
  - Jupyter Notebooks
  - Data Portal design
  - TRL assessment
  - Service evaluation
  - Service documentation
- EOSC Future
  - Designing and delivering the course “AG2.7 Service documentation for providers”, work in progress (M.Hellström, H. Lankreijer)
- Academic settings
  - Co-authoring "How to be FAIR with your data"[4], a teaching and training handbook for higher education institutions (M. Hellström)
  - Delivering NNG006F: Introduction to research data management”, a post-graduate-level course for Lund University Faculty of Science (M. Hellström, H. Lankreijer)
  - Contributions to RDM activities at Lund University Dept of Physical Geography and Ecosystem Science (M. Hellström, H. Lankreijer)

Management

Human resources

During 2022 the average work force at CP was 16.5 full time equivalents divided over 21 persons. In 2022 two persons left Carbon Portal and Lund University because they found another job. By 14 June this was Maria Johnson from the university library, who had worked for 25% for CP, and by 1 April developer Roger Groth, who had worked from CP from the start, at 50%. To replace Roger we hired a developer starting 1 March, but that proved to not work out so before the probation period we had to say goodbye at 1 June. After that we opened the position again, now focused on either another software developer or an operations engineer, but to date we did not find a good candidate, despite in total three application rounds and many interviews. We did find a good person for the open position for the work in the eDice project. Per 1 August we hired Arndt Meier as post-doc to work on the inversion demonstrator in that project. When he finishes that work in spring 2023 he will also work in the AVENGERS project for Marko Scholze’s group at the department.

[4] C. Engelhardt et al. (2022). How to be FAIR with your data. Universitätsverlag Göttingen, 214 pp. ISBN 978-3-86395-539-7. DOI https://doi.org/10.17875/gup2022-1915

International cooperation

TRANSCOM meeting

On September 16th and 17th, a TRANSCOM workshop was hosted in hotel de Wageningsche Berg, and co-organized by the ICOS CP teams from Lund and Wageningen (Alex, Wouter, Remco). Over a period of two days, a series of short talks around four themes were presented, addressing the recent CH_4 growth rate, urban monitoring, multi-tracer inversions, and common projects such as GCP and RECCAP2. A total of 94 participants joined the room in Wageningen, while another 52 attended the meeting online. Preference on the program was given to young, first-time speakers at a TRANSCOM event. We also tried to ensure diversity in gender and geographic origin of the speakers (nearly 20 nationalities were represented in the auditorium). Ample time for discussion led to a lively atmosphere, with regular exchanges between modelers and experimentalists. Many ICOS scientists and station managers were also present, as the meeting preceded the GGMT event the next day. A dinner, and wide range of social activities completed a very fruitful community event.

GGMT meeting

Following the TRANSCOM workshop, CP organised at the same venue the 21st CO_2 and Related Tracers Measurement Expert meeting of WMO GAW (GGMT). This was a three day meeting with a really full program. In person the meeting had 122 participants, with another 66 online participants. Sessions of the meeting handled QA/QC (separate sessions per gas and for isotopes), emerging measurement techniques including low-cost sensors and remote sensing, urban and regional observations and modelling, data productsand applications, and mobile platforms. Traditionally the concluding session was a discussion meeting for the update of the meeting report that also forms the list of recommendations for performing measurements and necessary improvements of the WMO GAW greenhouse gas observation network. A special topic of discussion at this meeting was the initiative by WMO to start coordination of a global operational Greenhouse Gas infrastructure and for the community to respond to this.

WMO GAW, GGMI

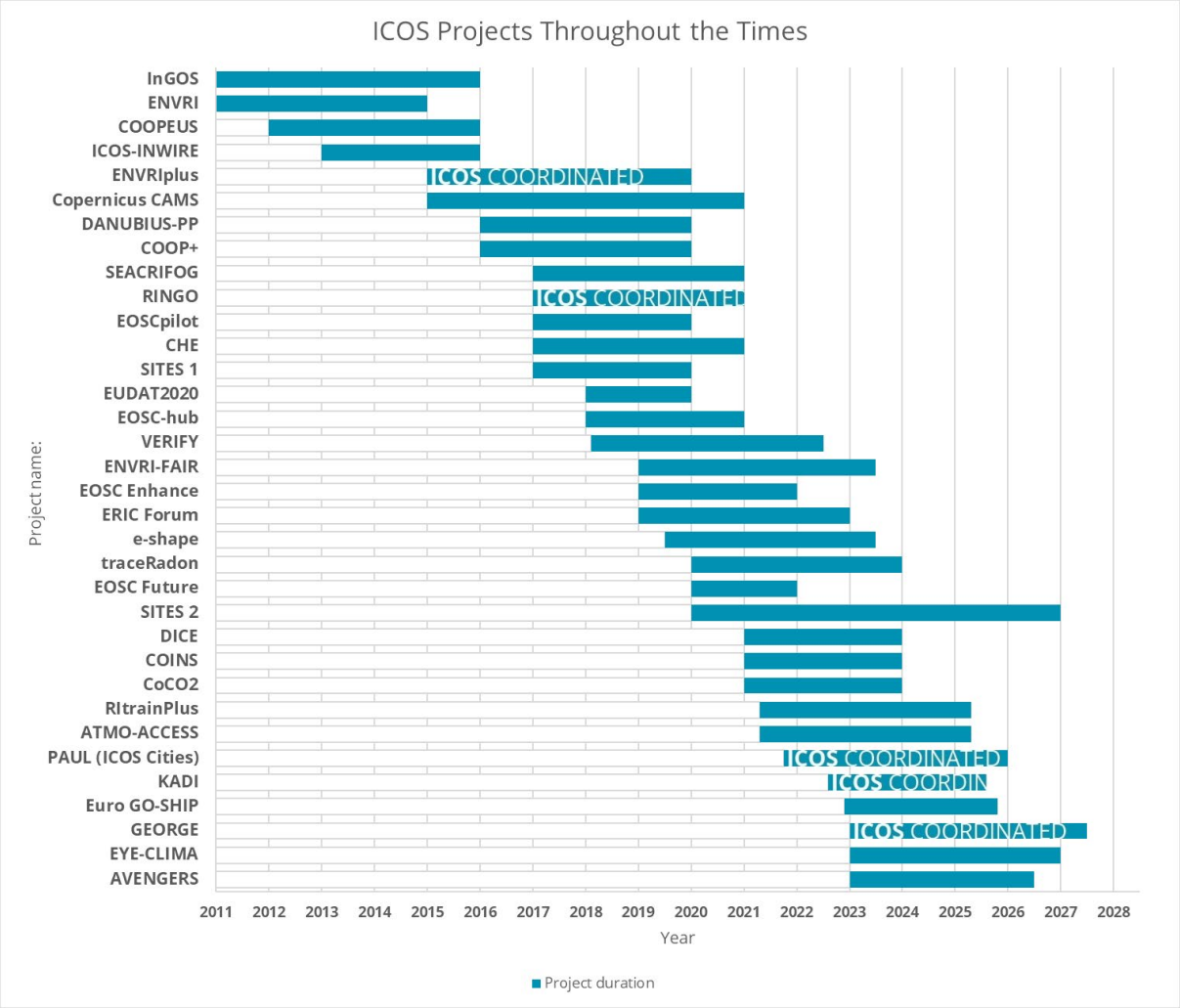
Also during 2022 CPD served as chair of the WMO GAW Scientific Advisory Group (SAG) for greenhouse gases, and from this function also member of the WMO GAW Scientific Steering Committee (SSC). He was also member of the WMO GAW SAG for applications (SAG-App) and the

WMO Expert Team for Atmospheric Composition Data Management (ET-ACDM). The GHG SAG coordinates the greenhouse gas activities in the WMO GAW network, approves new stations, coordinates the GGMT meetings and the annual WMO Greenhouse Gas Bulletin. This years 18th WMO GHG bulletin (WMO, 2022) focused on the still uncertain causes of the unprecedented rise in CH_4 concentration in 2021 and the positive confluence of the Kigali Amendment of the Montreal protocol on the reduction of potential warming in 2100 compared to the baseline and current policy scenarios.

Another important development in WMO is the initiative to start to coordinate an operational global Greenhouse Gas Monitoring Infrastructure. End of March WMO organised in Geneva a workshop to discuss this with the global observations and modelling community. This operational integrated global greenhouse gas monitoring infrastructure is modelled on the global weather system that would enhance climate data quality, consistency and availability, opening opportunities for researchers to improve significant uncertainties in our knowledge of the global greenhouse gas cycle. It also is directed at parties to the Paris Agreement to track their emissions better, see what ends up in the atmosphere, and assess the efficiency of their climate actions in near real-time. Setting up such an infrastructure is a global challenge requiring better cooperation and interoperability. By providing high-resolution data at a high frequency, the future GGMI would contribute to creating new research paths for scientists, aiming at reducing knowledge gaps about the Earth's climate. The increased density of the in situ observation network needed to achieve the high resolution will increase data availability from currently uncovered areas. This newly available data would serve as reference points for remote observation systems, as input to improve data-driven models, and as validation data for model predictions, increasing the actionability of the model data and helping scientists to understand the Earth's carbon cycles better.

CPD participated in the Geneva workshop and the assembled Study Group of about 20 experts that after the workshop further developed the concept in a more detailed working document, with the help of task groups that involved a further 100 experts, with quite some members of ICOS providing input. CPD led the task group on the observation requirements in relation to the modelling. This document has been presented and discussed at a dedicated Greenhouse Gas Symposium organised in January 2023 with more than 200 representatives from all relevant parties like Copernicus, European Commission, ESA, NASA, JAXA, NIES, IODE, Global Carbon Project, UNFCCC, UNEP, etc. The Symposium statement and the resulting report from the Study Group will be presented to the WMO Congress in May 2023 for adoption, and when this has been, as expected, adopted the implementation will begin. ICOS is seen as a blueprint and role model for how the in situ component of this GGMI should be organised through regional centres. ICOS is the only organiation world-wide that delivers operational and near-real time greenhouse gas obrservation information, and does this integrated over the three relevant domains, for atmosphere within the compatibility goal of WMO GAW and through free and open (FAIR) data access.

Projects



In the following, the progress of projects where ICOS ERIC participates is described briefly. Participation of different elements of ERIC is indicated (HO = Head Office, CP = Carbon portal).

ATMO-ACCESS - Solutions for Sustainable Access to Atmospheric Research Facilities (CP as ERIC and Lund)

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, lead 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 transport-models, 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.

AVENGERS (CP as ERIC and Lund)

Starting in 2023. Follow up of VERIFY with stron modelling focus.

CoCO2 - Prototype system for a Copernicus CO2 Service (HO and CP)

The CoCO2 project, coordinated by ECMWF and spanning from 2021 to 2023, will deliver the prototype systems for a new European anthropogenic CO_2 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 2022, the second deliverable of WP7, *Report of data availablity*, was completed, and material for next version of *Book Of Requirements* was collected by interviewing modelers in other WPs.. 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.

ENVRI-FAIR - ENVironmental Research Infrastructures building Fair services Accessible for society, Innovation and Research (HO and CP as ERIC and Lund)

ICOS CP has the leading role in the ENVRI-FAIR WP5 and WP6 and the CP representatives are involved in all WP5-WP6 tasks, both at cluster and subdomain level, as well as in technical tasks in WP7 and subdomain tasks in WP(8-11). Since the beginning of the project, monthly virtual WP5 meetings are organized by ICOS CP with representatives from most of the project WPs to regularly report on the project progress and coordinate the tasks among the participating RIs. The six (6) cross-domain thematic groups (Task Forces, TFs) formed in 2020 (corresponding to commonly identified targets within the ENVRI cluster) continued with their work, offering recommendations to the participating RIs and helping the project managers with several tasks. ICOS, having the leading role of WP5, has the responsibility for managing the TFs, following their progress, reporting back to the community and contributing to the harmonization of the different tasks and decision making wherever required. The CP participates in most of the TF virtual meetings representing ICOS, sharing experience (in the TF working groups or in surveys distributed by the TFs that investigate the ENVRI landscape) and taking actions for developments that are required by the project (leading the PID TF, working closely with the TF on the citations and licences, working on the mapping of the ICOS services metadata into DCAT-AP standards, delivering the ICOS FIPs). Additionally, ICOS CP having the leading role in WP6 has the responsibility of coordinating the training activities that are required to help the ENVRI partners complete their tasks (e.g. workshops on FIPs) and the organisation and execution of the ENVRI International Summer School, together with the WP6 co-leads from LifeWatch. ICOS CP works closely with the ENVRI-Hub developers for the design of the ENVRI-Hub, coordinating discussions and activities on the Hub components, demonstration of usability, design of the front-end and general architecture and taking the lead for the better integration of the training resources into the Hub by coordinating the developments on the

"training gateway", in collaboration with the training catalogue metadata team in LifeWatch. ICOS CP finally contributes to 3 out of 4 subdomain WPs by providing the ICOS FIPs for the subdomain tasks on FAIRness, as well as the necessary metadata and services for the development of the subdomain use cases (scientific demonstrators).

Some of the ENVRI events where the ICOS CP participated in 2022 include the ENVRI week (organising WP5-WP6 sessions and contributing to the subdomain sessions), the ENVRI-FAIR review meeting, the EGU22 GA (participating with abstracts and contributing to the ENVRI exhibition booth), the ENVRI International Summer School (organising the topics, the school format, teaching on-site and remotely, inviting speakers for the training sessions), the TF6-ENVRI-Hub f2f workshop (organising and chairing the workshop), the TF1 ENVRI Catalogue hackathon (participating in the discussions and work with mapping the ICOS service metadata into DCAT-AP), the FAIR Convergence Symposium at the 1st FDO Conference (participating in a symposium panel and representing ENVRI-FAIR), the EGU23 session submission (co-convening a session) etc.

EOSC Enhance - Connecting Thematic Communities to Advance Open Science (CP as ERIC)

CPD represents the ENVRI-FAIR project to follow the further development and specification of the EOSC (European Open Science Cloud) 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 ENVRI-FAIR through its WP5.

EOSC Future - Advancing European research through Open Science (CP as ERIC)

ICOS CP has the leading role at the Science Project 2 (SP2) of the EOSC Future, the Dashboard for the State of the Environment. The ENVRIs participating in this project build analytical workflows that give access to their data and services and provide environmental indicators that populate the environmental Dashboard, a new service that is being developed by the ENVRIs on the EOSC platform. ICOS CP has the responsibility of coordinating the development tasks to deliver the Dashboard and has taken initiatives for the engagement plan and for promoting the Dashboard using the existing ENVRI channels and strengthening the links between the ENVRIs and the EOSC. ICOS CP contributes to the demonstration of the Dashboard, provided the first prototype of the new service which was further developed by EMSO, works on the workflows that will bring the ICOS indicators to the Dashboard and will give the EOSC users the possibility to access the ICOS data, products and services. Several ICOS services have been onboarded on the EOSC platform during 2022, aiming at increasing ICOS visibility. ICOS CP is also active in WP9 working on training activities (webinars, guidelines etc.), and coordinates the development of training material for the ENVRI Dashboard in SP2.

During 2022 ICOS CP has represented the ENVRI Dashboard and the ENVRI cluster in several EOSC meetings, including the EOSC Future meetings where the SP2 was presented and demonstrated, the EOSC Symposium (invited talk for SP2 demonstration), the EOSC Future review meeting (the ENVRI Dashboard was one of the leading use cases and was chosen to be demonstrated for the reviewers), training activities on service description etc. An important task in the EOSC Future project is the integration of the service providers in the EOSC. ICOS CP is playing an important role in this task, taking the initiative (together with MARIS) to compile the ENVRI integration matrix and motivate the ENVRIs to strengthen their links with the EOSC. Workshops with the core services and the ENVRIs are organised with help from ICOS CP

ERIC Forum (HO)

In the ERIC Forum project, ICOS ERIC led a task in a work package about the ways to measure and convey the socio-economic impact of ERICs. Furthermore, ICOS ERIC provided the project website and email lists, and continued to develop an online toolbox which will gather the results of the project to an 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 ERIC also participated in discussions and planning related to a follow-up project that aims to further strengthen the position and voice of ERICs as a united body and continue to harmonise managerial processes across the ERICS.

E-shape - Shaping the EuroGEO initiative and delivering EO-derived benefits with and for users (HO)

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 2022 the project produced the second version of global terrestrial carbon fluxes and a comparison of data driven product (FLUXCOM) to the two top down derived estimates based on remote sensing approach. FLUXCOM derived estimates were compared to O-CO2 satellite anomalies and Copernicus Atmospheric Monitoring Services in TRANSCOM regions. All partners and domains in Global Carbon and GHG Emissions pilot also submitted their Python based codes to ICOS Carbon Portal Jupyter hub.

EuroGOSHIP (HO and CP as ERIC)

Started 1.12.2022 The project aims to support a programme to address ocean observation gaps within the context of the European RI landscape.

EYE-CLIMA (CP as ERIC)

The project shall address this need for independent verification by developing observation-based methods using both satellite remote sensing and ground-based observations

GEORGE – Next GEneration multiplatform Ocean obseRving technoloGiEs for research infrastructures **(HO)**

GEORGE Grant Agreement (GA) preparations started immediately after the summer vacations. First GA-meeting was organized via the zoom with all of the WP and ERIC leaders at August 19th, 2022 and the first interim EB meeting composed from WP and ERIC leader meeting was held in August 31st, 2022. After which, the HO project management team (Janne-M. Rintala and Emilie Hachem) carried out independently throughout the autumn and successfully executed the Grant Agreement. Necessary changes made since the submission of the proposal included addition of ethical self-assessment and adding of a new work package 8 for Ethics. Major changes made to consortium structure was that all of the UK beneficiaries were changed into associated partners according to the instructions received from the EC Research Executive Agency, Project Officer, Emilino Carrozza. In the beginning of 2023 Deliverable 8.1 "Appointing an external Ethical Advisor" was written and submitted in a timely manner to the EC. Management team also drafted two big documents, an Consortium Agreement and an NDA for External Expert Advisory Board members were prepared. The project has had five WP and ERIC leader meetings in 2023: Jan. 12th, Jan. 19th, Feb. 2nd, Feb. 16th and March 2nd respectively to discuss ongoing project matters and to plan the Project Kick-off meeting, which will be held virtually via the Zoom in March 15th

and 16th. Work package 5 has organized one planning meeting in March 7th to plan future demo-missions and work-packages 2-4+6 organized a separate workshop in March 8th at Southampton to plan and synchronize all of the future activities. This meeting also had a remote participation.

GEORGE started in January 2023 and it has funding for 54 months and a total budget of ca. 10Milj.€.

KADI - Knowledge and climate services from an African observation and Data research Infrastructure (HO)

The KADI project started on September 1st 2022 and had its kick-off meeting in October in Johannesburg (South Africa). The 16 partners (5 from Africa) were all represented at the meeting that defined the work program for the first year of the project. The project was also presented at the following 36th annual meeting of the South African Society for Atmospheric Sciences hosted by the Global Change Institute of the University of the Witwatersrand.

PAUL (ICOS Cities) - Pilot Application in Urban Landscapes towards integrated city observatories for greenhouse gases (HO, CP)

After the kick-off (see highlights from the Annual Report 2021) the project had a very succesful first year and is on course to deliver. ICOS Head Office and the Carbon Portal are pivotal to the coordination, communication, and data management and involved in almost all the work packages. Project internal communication channels, email lists, logos, website (https://www.icos-cities.eu), templates, regular meetings, etc are established. Monthly executive board meetings help to keep track on progress and highlight any arising challenges. We have recruited a scientific advisory board with international recognised scientists, covering topics in social sciences, emissions inventories, measurements and modelling of GHG in an urban landscape. First deliverables have been produced and are available on the website. Since this project has a focus on a co-design approach, we have put a lot of effort to engage city representatives and stakeholders from outside the academic world. This resulted in an ongoing series of webinars (ICOS Cities Talks) exploring and presenting topics and challenges around Urban GHG Monitoring and Verification services (UMVS). These talks have attracted 50-100 participants in average and are very well received.

The main achievement from the first year in a nutshell:

- The observatory of Zurich is fully operational. Paris is at around 90% finished and Munich is getting all the knowledge and lessons learned and is building up the measurement infrastructure. The overall lesson learned from building up a urban research station is, that location is one of the most important factors, and getting permission the install instruments.
- - A first version of high-resolution city emission inventory for GHGs and co-emitted species is available. This is crucial as input to the modelling efforts which will be ramped up in the second year.
- - An integrated tool capable of mapping future emissions based on city climate plans and urban development plans was developed as a QGIS plugin.
- - The first wave of questionnaire is now available through our partners with the European Social Survey RI and will be sent out in summer 2023.
- - An analysis of climate governance structures and emission inventories for cities and available data was produced
- - Interviews with stakeholders from all three Pilot cities are in progress

RItrainPlus - The Research Infrastructure Training Plus (HO)

Building on 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 workpackage).'

SITES - Swedish Infrastructure for Ecosystem Science (CP)

Already since 2017 the national measurement infrastructure SITES in Sweden makes use of the Carbon Portal concept through their own instance of the Carbon Portal software (see https://data.fieldsites.se/portal/) . The SITES project funds 0.6 FTE at CP and through this co-development both SITES and ICOS profit from joint developments and experiences, through the extended user base and use cases of this combination. SITES applied for an extension of their operation through the Swedish national road map and has now secured funding until the end of the year 2028. SITES and ICOS CP have now agreed to extend the existing agreement on the cooperation over this period.

traceRadon - Radon metrology for use in climate change observation and radiation protection at the environmental level (CP)

A process-based radon exhalation map for Europe based on state of the art soil moisture reanalyses and the latest version of the European soil uranium content map was developed for the use in atmospheric transport models and application in radiation protection. The map is available as elaborated product in CP.

VERIFY - Observation-based system for monitoring and verification of greenhouse gases (HO, CP)

VERIFY project had its final meeting in May 2022.

The aim of the H2020 VERIFY project was 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 had 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, started in 2021.

Atmosphere Thematic Centre (ATC)

Task 1. General management

ATC Data Processing unit and Malb meet on a weekly basis; ATC as a whole on a monthly basis.

ATC director attended all RICOM meetings and ICOS GAs and performed the required reporting. ATC is also largely involved in the MSA Atmosphere that take place twice a year.

HIGHLIGHTS:

- Centralized quality managmetn system operational
- Publication of Obspack Europe with the CP

Task 2. Data management / production

Task 2.1 Level 0 data transfer

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

- The French Romainville and Meudon stations used within the PAUL project have started to transfer GHG data and meteorological data.
- The Spanish Izaña station has started to transfer GHG data and meteorological data.

Maintenance

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

Developments

- Java and libraries migration of all the processing chains.
- Developement of the new chain to process the CAL flask data and allow the manual quality control of the data by the PIs.
- Update of the Picarro processing chain, the interpolation of the water vapor correction factors has been implemented and the data of 2 pilot stations have been reprocessed.
- Finalization of the chain processing the radon data from the Heidelberg radon monitor. Processing of the historical data.
- Development of a new chain to process data the European Obspack project compiling atomospheric CO2 and C from ICOS an non-ICOS European stations. Addition of new concepts also added to ICOS (combination of historical sampling heights, use of a dummy instrument associated to periods without data).
- Updates of the metadata to take the information of the European Obspack project into account.
- The weekly GHG data reports for the Pis have been enhanced, addition of a report for diagnostic data.
- Updates of the role system to combine roles for ICOS and the European Obspack project.
- Update of the metadata automatically sent to the Carbon Portal as well as the metadata send along with the L2 data.
- Evolution of the graphical applications:
    - Update of the instrument history display in the ATCConfig.
    - Updates and new functionalities added to the ATCQc related to the flask data: display, quality control and display of linked in-situ data.
- Finalization of the international CO2 scale update

Task 2.2 NRT data production

A total of 41 (+3 compared to 2021) stations are connected to ATC, sending their data to ATC and, consequently, are able to be processed in NRT mode. This represents 18954 (+21% compared to 2021) raw archive files (~144Go, +xx% compared to 2021, for a mean of xxMo/station/day) processed for an availability rate of ~0.99 (+compared to 2019) for 35 (+6 stations compared to 2021) stations which transmit their data over the complete 2022 year.

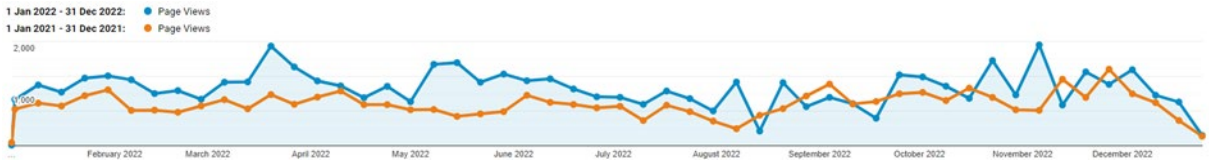
Task 2.3 NRT data visualization and distribution.

NRT data visualisation can be accessed on ICOS ATC website [https://icos-atc.lsce.ipsl.fr/dp], 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 2022, 60 families of graphical NRT Data Products, (~ 4357 products in total, which represent an increase of 47%/2021, for ICOS network stations) are produced daily from NRT measurements (total volume of 1.21Go (+0.47Go/2021) and freely available on the ATC website for station monitoring and diagnosis.This increase is mainly due to new products related to the QA panelboard available on ICOS ATC website, and some new products declined to ICOS sub-networks.

Those Data Products are for PIs to verify the status of their stations. In total, for the year 2021, nearly ~ 4,414 (+46%/2021) users have interacted with ATC's website, for ~ 57,612 (+38%/2021) page views.

Figure: Page views for 2022 (in blue), compared to 2021 (in orange).



Task 2.4 Level 2 data production

The new Level 2 (2022-1 release final quality controlled observational) data from the atmospheric network has been released on July 2022 by the ICOS Atmosphere Thematic Centre. This 2022-1 release containing data from the atmospheric network of ICOS Research Infrastructure for 36 stations and 86 vertical levels at Birkenes, Gartow, Helgoland, Hohenpeißenberg, Hyltemossa, Ispra, Jungfraujoch, Jülich, Karlsruhe, Křešín u Pacova, La Réunion, Lampedusa, Lindenberg, Lutjewad, Monte Cimone, Norunda, OPE, Ochsenkopf, Pallas, Plateau Rosa, Puijo, Puy de Dôme, La Réunion, Ridge Hill, Saclay, SMEAR-II Hyytiälä, Station Nord, Schauinsland, Steinkimmen, Svartberget, Torfhaus, Trainou, Utö - Baltic Sea, Westerland, Weybourne and Zeppelin Observatory.. This collection contains the final quality controlled hourly averaged data for the mole fractions of CO_2, CH_4, N_2O, CO and meteorological observations measured at the relevant vertical levels of the measurements stations, also available ^{14}C in CO_2 in two-weekly integrated samples, for the period September 2015-February 2022. 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). https://doi.org/10.18160/KCYX-HA35

First official release of the European Obspack project compiling atomospheric CO2 and C from ICOS an non-ICOS European stations for the period 1972-2022.

European atmospheric CO2 and CH4 Mole Fraction data product -2022. https://doi.org/10.18160/1re0-2gkh

Task 3. Network coordination, training and development

Task 3.1 Perform instrument testing

In 2022, the ATC Metrology Lab (MLab) has kept a regular workplan. 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, H_2O correction. ATC MLab has provided a test report and a certificate of compliance to all the instruments tested. Moreover ATC MLab has performed technology watch activities with a few new analyzer testings. Indeed, the MLab has tested the new N_2O analyzer LI-7820 from LICOR using the OF-CEAS technology, a N_2O CO_2 analyzer from AERIS and a CO_2 CH_4 N_2O analyzer from AP2E. ATC has initiated in 2022 the assessment of the version (rackmount) of FTIR Spectronous in order to verify if this version can figure within the ICOS compliant instrument list like the initial version. ATC MLab has also continued the assessment of multispecies QCL spectrometer from MIRO able to measure GHG (CO_2, CH_4, N_2O, H_2O) and Air Quality compounds (NO, NO_2, O_3, CO, NH_3) at high frequency in order to potentially open the field of application to the flux measurement (by eddycovariance) in addition to the accurate and precise concentration measurement. The performance was presented during the second MSA in 2022 and will continue in 2023 especially in the ICOS-Cities project.

To further investigate the 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 issues. Indeed, ATC MLab has implemented additional quality control tools and internal dataproducts as well as an automatic data processing chain interfaced with the ICOS data base and the WebObs[5] 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. As the change of the new water vapor correction involves a large data processing, the implementation has started in March 2023 and is currently smoothly generalized to all the ICOS stations.

ATC has tested the possible bias on CO related to several Nafion dryer in different conditions. The phenomena only concern few Nafion dryers in specific temperature conditions (high temperature). In consequence, ATC has communicated with the station PI (during MSA and data review meeting) about this possible issue. The automatic quality control currently in place on the ATC server is able to detect such issue by discarding the calibration in CO.

ATC has studied the overall CO2 bias observed on the short and long term target (quality control gas) measured in the whole ICOS network in order to check the representativeness of such information and detect possible related issue such as Nafion artifact. The study did not show systematic issue related to the tank assignment. However, it highlights the small residual bias related to dryness of the measurement cell. However, thanks to a required operating procedure specified in the ICOS specifications document (version 2.0), ATC is able to estimated this bias for the overall uncertainty (still in progress). This study will be conducted on CH_4 and CO in 2023.

ATC has provided a Standard Operating Procedure (SOP) specific for N_2O measurement in order to improve the measurement performance. Indeed, as the intrinsic performances of the N_2O analyzers

[5] On webobs, see also task 5

available on the market and selected by ATC, are often limited and insufficient to fulfill the ICOS quality objective, it is important to optimize as much as possible the operating procedure.

Once the stations are labelled, ATC carries on controlling the quality of the data provided by the station by checking the corresponding ATC data products 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 CH_4 Metal Oxide sensor, Axetris LGD CH4 This prospective work takes place for new domain of application (mobile measurement, dense low-cost sensor network for urban area or industrial site…). This work part of ICOS-Cities-PAUL focusing on CO_2 emission in 3 urban areas: Paris, Munich and Zurich.

Task 3.2 Perform atmospheric station audit

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 greenhouse gas measurements at ICOS atmosphere stations (AS). Aim is to improve measurement compatibility and development of quality assurance (QA) of the ICOS AS network that ensures credibility of the measurements.

Due Covid-restrictions for travelling, the Mobile Laboratory did not perform audit during the first half of the year 2022. Class 2 station Puijo (PUI) was audited in autumn 2021, and the report was finalised during the year 2022. In autumn, the Mobile Laboratory performed an audit for the class 2 ICOS station and GAW station Reunion (RUN), simultaneously with GAW audit. RUN audit was performed with simplified instrumentation due the challenging location of the station.

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.

Task 3.3 Perform training activities for ICOS atmospheric measurements

ATC has organized one in-person training. The attendees of this training were Pis/Staff from Hungary, Denmark and Spain. It lasted over 3 days.

All the initial training requested for new ICOS incomers 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 trainings might be online and face-to-face meeting at LSCE (more suitable for experimental practical work)..

Task 3.4 Station Labelling

The ATC workplan, reports and associated budgets were provided to ICOS HO. Labelling of 2 new ICOS Atmosphere stations in 2022: Schauinsland and Ridge Hill.

Task 4. Projects and international cooperation

ATC is involved in the following EU porjects: ENVRI-FAIR, TraceRadon, Atmo-Access, PAUL/ICOS cities.

Task 5. Other activities

Webobs is a web application for monitoring and managing atmospheric measurement stations, developed y AC. It provides support to station managers of the ICOS network and other networks to

assist them in the maintenance of their stations. With Webobs user-friendly interface, the station manager can easily manage inventory, track equipment and tanks, add station events, and collaborative tools such as troubleshootings and tests performed on the instruments on stations.

In 2022, WebObs has been migrated from Symfony2 to Symfony5!

This involved updating the codebase, replacing deprecated functions, and modifying configuration files to ensure compatibility with the latest version of Symfony. Also, the opportunity is taken to refactor the codebase, optimize performance, and clean up any technical debt. The migration to Symfony5 ensures that WebObs is now running on a secure and up-to-date framework, providing improved stability and security for the application.

ATC is pursuing its activity to get accredited with the ISO norm 17025 for the instrument testing activity of the Mlab

Yi, Hongming & Laurent, Olivier & Schilt, Stéphane & Ramonet, Michel & Gao, Xiaoming & Dong, Lei & Chen, Weidong. (2022). Simultaneous Monitoring of Atmospheric CH 4 , N 2 O, and H 2 O Using a Single Gas Sensor Based on Mid-IR Quartz-Enhanced Photoacoustic Spectroscopy. Analytical Chemistry. 94. 10.1021/acs.analchem.2c03785.

Ecosystem Thematic Centre (ETC)

Task 1. General management

Task 1.1 Management and provision of the ETC and the related IT and data management

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

Internally, the ETC worked on evaluating and analysing the current financial situation and concluded that this needs to be more robust. A series of possible financial scenarios have been prepared and discussed first among the ETC scientific leadership and then with the Italian, Belgian and French GA members to arrive at a common position to present to the GA.

Task 1.2 Reporting

The activity and financial plan for 2023 and the report of the 2021 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.

Task 2. Data Management / Data production

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 the labelling procedure submitted data and metadata. Vegetation samples and soil samples have been shipped by 28 and 3 stations to the ETC labs in France for analysis, a number increasing every year with the new stations labelled.

Level2 data have been produced and distributed through the CP, including the Interim version released after the growing season and introduced last year. Near Real Time data production and release continued and the data release cover the period from the last Level2 release to the current day.

Task 2.1 Raw data collection and transfer, including their metadata

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, particularly 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 1322 vegetation samples shipped to the ETC (they were 671 in 2018, 934 in 2019, 989 in 2020 and 1242 in 2021) for the analysis and all the samples have already been analysed and imported into the database. In addition, more than 500 soil samples have been shipped for analysis in 2022 and are under processing. The soil samples are stored in the long-term facility for 15 sites.

Task 2.2 From raw data to Level 1 data

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

Task 2.3 Level 2 data production.

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, also supported by the GA, a second processing period has been defined at the end of the growing season for both the continuous (fluxes and meteorological) and ancillary data. The product, named Level2 Interim, deprecates the official Level2 released in spring, and it is deprecated by the new official Level2. This has been in production since 2021.

The metadata provision has been improved with a system of Api for a rapid exchange and update of the metadata from the ETC to the CP. The APIs provide all the information needed to assign PIDs to every single sensor and link the sensor to the variable originated. This is a major improvement in the system, it has been tested in three sites and a few complex variables and is currently under extension to all the other variables.

Task 3. Network coordination, training, and network / RI development

Task 3.1 Support and training for a correct implementation of the ICOS protocols.

One Instruction document has been revised, clarified and updated in 2022, and 6 BADM templates for the ancillary data have been revised and improved. The sensors listed in the ETC with a unique identifier arrived at 336 models. Continuous support has been provided to the stations' teams to optimize the data and metadata submission. Feedback time on specific requests is generally less than 36 hours and commonly within 24 hours.

Task 3.2 Method evaluation, optimization, evolution and development

A new Instruction document has been finalised and released for the measurement of Transmitted radiation that can also be used as an alternative method for the GAI estimation, avoiding the use of DHP in sites where it is complex to find the suitable conditions.

In addition, a vital guideline document has been released, after discussion and exchange with the Ecosystem MSA, on the update of protocols. The document describes step by step the procedure to change the ICOS methodologies to keep the maximum level of quality and consistency in the timeseries without missing the opportunity to use new methods, sensors and approaches.

Task 3.3 Station Labelling

The activities on the labelling continued in 2022 with stations that entered the process and stations proposed for labelling. In particular:

- Two stations started the labelling procedure (FR-CLt and GL-ZaH), and both completed the Step1
- Fifteen stations completed the labelling in 2022: 2 Class1 (CZ-Lnz, FR-Hes,), 8 Class2 (BE-Dor, CZ-BK1, FR-FBn, FR-Lqu, FR-Lus, GL-ZaF, IT-MBo, SE-Sto) and 7 Associated (CD-Ygb, DE-BeR, DE-Har, DE-Msr, DE-RuW, GL-ZaH, IT-Niv)
- There are only 7 Class1 and Class2 stations (excluding the stations entered in 2023) that didn't complete the labelling yet and the status and comments about the situation of each station are added in the labelling Carbon Portal interface.

Task 3.4 Support on ecosystem data interpretation and use

The activity still need to be organised systematically. Support on data use has been provided on single and specific requests, except for the Remote Sensing CalVal activities (see Task 5)

Task 4. Projects and international cooperation

The ETC Director (Dario Papale) participates in the FLUXNET Co-Op, a US initiative to coordinate the activities in the context of the regional ecosystem fluxes networks. In this context a specific Working Group has been organised under the ICOS coordination to implement a standard basic processing and sharing system across the Regional Networks (in particular ICOS, AmeriFlux, NEON and OzFlux at the moment).

Task 5. Other activities

A specific action has been continued and improved to link the ICOS ecosystem network with the CalVal Remote Sensing activities. In this context specific meetings have been organised to show the potential of the ICOS data and support how these data can be accessed, used and correctly interpreted.

Ocean Thematic Centre (OTC)

The current status of the OTC is that it is a partnership between four institutions employing 5.5. FTE. The detailed list is as follows:

- 0.5 FTE at University of Exeter covering project management and international engagement (Andrew Watson, Nicole Dalton)
- 2.1 FTE NOC (In kind effort from Socratis Loucaides + Technology programme in NOC)

- 1 NORCE (Leadership, Richard Sanders, 0.3, Labelling, Ingunn Skjelvan, 0.2 Training and Station Support, Tobias Steinhoff, 0.5)
- 2 University of Bergen, (Data, lead by Steve Jones)

This staff list reflects several changes that have taken place in recent years as follows:

- Departure of Erik Sandquist (Project Administrator, NORCE) to University of Bergen, replacement by Ryan Weber
- Departure of Jess Thorn (Project Support) to another post in the University of Exeter, Replacement by Nicole Dalton
- Departure of Benjamin Pfeil + 2 other staff from University of Bergen to Norwegian School of Economics and Marine Institute. Recruitment effort by the University is underway which has now delivered a replacement.

Task 1. Leadership and management

In addition to the core tasks associated with this workstream (reporting, planning, communicating) we engage in a wide variety of international and continental activities with the general objective of integrating ICOS tightly into the international agenda and improving the funding situation for stations. These include:

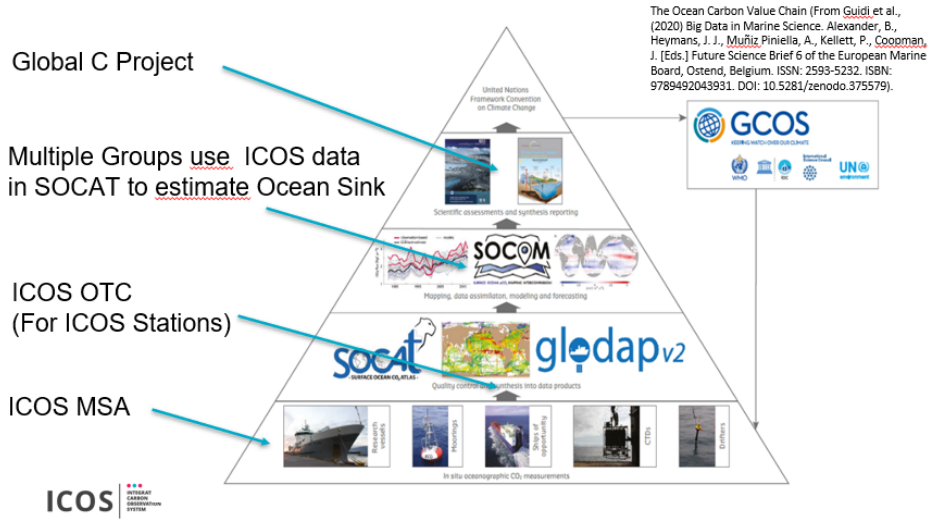
- We are leading an action within JPI Oceans called Ocean Carbon Capacities. The objective of this is to increase the observational footprint of carbon observing in European waters and to strengthen the value chain that ICOS stations rely on for their route to impact (See Figure below). Engagement continued throughout 2022, culminating in a meeting in person in late 2022 in Brussels. The workshop lead to a series of specific actions around supporting SOCAT, deep ocean CO2 standards and equipping research vessels in key regions. A paper summarising key actions has been prepared and will be considered at the JPI Oceans Management Board meeting in April.

- Surface Ocean pCO_2 system operations. The ICOS station network forms part of the European component of the global surface ocean pCO_2 observing system which contributes to quantifying surface Ocean CO_2 uptake. In recognition of the importance of this network several organisations are beginning to make efforts to stabilise and enhance this and to raise its profile in the international arena.

- We are strongly engaged in the WMO Greenhouse Gas initiative (Global Greenhouse Gas Monitoring Infrastructure – Developing the Concept | World Meteorological Organization (wmo.int))which is likely to become the fora where international coordination occurs and in the community dialogue which is likely to shape the way that the system is designed and how it sits within GOOS, the Global Ocean observing System. Specific actions include:
  I) contributing to the IOCCP and G7FSOI task team on designing a surface ocean pCO_2 system (Towards a global strategy for monitoring of Surface Ocean CO2 - collaboration between G7 FSOI and IOCCP) and
  II) contributing heavily to the WMO GHG planning process including writing the initial draft of the January 2023 Workshop statement.
- Finally, we maintain our engagement with the Integrated Ocean Carbon Research (IOCR) initiative (Integrated ocean carbon research: a summary of ocean carbon research, and vision of coordinated ocean carbon research and observations for the next decade - UNESCO Digital

Library) which is the key venue where Ocean C science priorities are identiofeid. In 2023 this is holding an in person meeting in Brussels sponsored by the commission specifically to increase the visibility of European Ocean C related efforts including ICOS.

- We are co-leading a UN Decade exemplar in the Ocean observing codesign programme focussed on scoping what the observing system of the future might look like (Ocean Observing Co-Design: Evolving ocean observing for a sustainable future – Ocean Decade). The challenge is that required to simultaneously measure both direct climate impacts and indirect impacts from industrial processes on the ocean c cycle. This links strongly to the OceanIUCUS grant and to Marine CDR issues being considered in the ICOS fluxes document.



Task 2. Data management/data production

During 2022 six stations were fully integrated into the standard OTC data workflow (processing and quality-controlling data in the standardised QuinCe software and submitting to the Carbon Portal), with initial integration started for a further three.

All required features are now in place for most SOOP stations to utilise QuinCe and OTC's data workflow, and for FOS stations with one type of sensor whose processing algorithm is known and standardised. As stations using that sensor pass through labelling and/or other operational issues, they will be added to the QuinCe workflow. Work is under way to establish the correct algorithm for another sensor used by the community in conjunction with the manufacturer.

During 2022 some key staff left OTC and there were extensive delays in finding replacements. This limited work in a number of areas. The planned overhaul of OTC's metadata systems was put on hold completely, while remaining staff had to step in to cover aspects of station support and station labelling, which in turn meant that QuinCe software development and maintenance work could not be continued to the extent expected.

Summary of published L2 observations for 2022:

Station	Observations
BE-SOOP-Simon Stevin	97638
DE-SOOP-Finnmaid	284339
FR-SOOP-France-Brazil	16236

NO-SOOP-G.O.Sars	121411
NO-SOOP-Trans Carrier	31928
NO-SOOP-Tukuma Arctica	114605

Task 3. Network coordination, training and development

Training and Network Support

ICOS stations tend to use one of two basic technologies to measure surface ocean CO_2 levels, systems directly caibrated to gas standards from the ICOS Calibration Laboratory and membrane based systems which rely on pre and post deployment calibrations plus any opportunistic comparisons made during station visits. We work hard to support both communities including via the provision of technical solutions to allow better calibration of buoy mounted systems and the provision of bespoke Software known as Quince to allow data processing of both data streams (see figure below).

Workup of Intercomparison: In 2021 the OTC lead an intercomparison of different pCO2 sensor systems at VLIZ in Belgium (1st ICOS OTC pCO2 instrument inter-comparison | OTC Carbon Portal (icos-otc.org)). This is intended to be published in summer 2023. The results will be used to update the current labelling document and be available as international resource supporting station operations by ICOS and others.

MSA Meeting at Ocean Science Conference in 2022. We organised a MSA meeting at the 2022 Science conference. The major agenda item was to discuss the results of an online poll amongst MSA members around which investments they would like to see from the unspent funds in support of station operations. The consensus view was that we should invest in a lowered calibration unit for buoy based stations that could also operate as a duplicate system for stations to use underway. We plan to initiate procurement and build during 2023.

Workshop: In summer 2022 OTC participated in the online SOLAS summer school providing a lecture about data processing. In December 2022 OTC organized a data processing workshop including QuinCe hands-on training in Paris/France.

Station Ringarounds: Between November 2022 and February 2023 we conducted the annual station ring around where all PIs are asked to participate. The results are a basis for the annual OTC workplan and

give a good overview over the network condition (in terms of funding and technical problems). A more detailed overview is available if required however the simple summary is that training, the supply of standards and advocacy emerged as key actions valued by the network alongside the opportunity to participate in proposals and the labelling process.

Labelling

The table below show the status of each of the ocean stations per November 2022, where green colour indicates that the station is labelled, black colour indicates ongoing or delayed labelling, while red colour indicates that the labelling is stalled. (NB since this several stations have been labelled and have been submitted for approval in spring 2023).

Station name	Labelling status	More information
BE-FOS Thornton Buoy	Step 3 APPROVED	2018
BE-SOOP Belgica	Step STALLED	The new R/V Belgica is operational from January 2022. pCO2 data is available and will be submitted early 2023
BE-SOOP Simon-Stevin	Step 3 APPROVED	2021
DE-FOS Cape Verde Ocean Obs.	Step 2 DELAYED	The station PIs have faced a variety of challenges on their way to get surface pCO2 measurements, e.g., several buoys got lost, breakdown of the vessel. They are still working towards getting the station ready for labelling
DE-FOS Hausgarten	Step 1 APPROVED	The mooring pCO2 sensor was lost in 2020. The site is remote and there are few opportunities to deploy new moorings, the next deployment is planned for 2022. Thus, no data will be available before summer 2023
DE-SOOP Atlantic Sail	Step 3 APPROVED	2022
DE-SOOP Finnmaid	Step 2 DELAYED	System with two CO2 sensors. Test of standard gas stability has been performed, and OTC is currently evaluating the first CO2 system. OTC still working with data processing for the second CO2 system
DE-SOOP Polarstern	Step 3 APPROVED	2020
ES-SOOP CanOA	Step 2 DELAYED	The CO2 system was dismounted in Fall 2021. The reinstallation was delayed due to late delivery of vital components. Now, the system is working and is about to collect the sufficient amount of data for labelling
FR-SOOP France-Brazil	Step 3 APPROVED	2018
UK-FOS Porcupine Abyssal Pla.	Step 2 DELAYED	Instrumental issues and challenging to collect sufficient amount of data for validation. Measurements from different deployments and different years are used to evaluate the station. Ongoing work

UK-FOS Western Channel Obs.	Step 2 STALLED	Has not been able to engage the PI, but from the web site, it seems that the station is active
IT-FOS PALOMA	Step 3 APPROVED	2018
IT-FOS E2M3A	Step 2 DELAYED	Instrumental problems at station, new buoy with sensors will be deployed by end of November 2022
IT-FOS Miramare	Step 3 APPROVED	2022
IT-FOS W1M3A	Step 3 APPROVED	2022
NO-SOOP Bergen Kirkenes	Awaiting STEP1	The ship is being repaired due to stranding and the CO2-system is being tested in the lab
NO-SOOP G.O. Sars	Step 3 APPROVED	2018
NO-SOOP Trans Carrier	Step 2 DELAYED	Due to instrumental problems, the CO2 system was upgraded and is reinstalled on the ship in April 2022. Shortly after, it was decided to replace the ship with Sea-Cargo-Express. The planning for new pCO2 installation is ongoing
NO-SOOP Tukuma Arctica	Step 3 APPROVED	2018
NO-SOOP Kronprins Haakon	Step 3 APPROVED	2020
SE-MFT Östergarnsholm	Step 2 DELAYED	High natural variability at this coastal location makes it challenging to use discrete data for validation purposes. PI has performed tank experiments in lab, still not able to meet ICOS criteria
SE-SOOP Tavastland	Step 2 DELAYED	The CO2 system is modified, new ferry box is installed, which does not work optimal, however, CO2 data collection for station labelling has started

Task 4. Projects and international (external) cooperation

International cooperation is detailed under Task 4. Project work in 2022 included finalising a ICOS relevant component to a small EU project CCVS which was aimed at improving linkages between the satellite and in situ observing communities and the submission of multiple Grant proposals to strengthen the network and to improve its linkages with end users. Successful proposals include the following:

- OceanICU. 15.7 M Eu lead OTC. Large grant focussed on understanding industrial and fishing impacts on C cycle. Key for ICOS is the inclusion of a ca. 2M component focussed on understanding the model data mismatch in the Global C project estimates of Ocean C uptake which exploits ICOS and other data. There are other elements supporting network design and integration into international activities.
- EuroGOSHIP. 3M EU lead by NORCE with heavy OTC and ICOS head office involvement. Aims towards integrating Hydrographic Sections into Reseearch Infrastructure landscape. Actions around system design and standards as well as funding agency liason.
- MARCO BOLO: EMBRC lead EU proposal on coastal biodiversity including element on Ocean C cycle (OTC element is ca 150K Euros)

- GEORGE: Head Office / OTC lead technology proposal focussed on building next generation snsosrs and integrating them into existing workflow. OTC element includes data and platform trials, plus international leadership. Multiple stations involved as demonstration platforms.

Central Analytical Laboratories (CAL)

Task 1. General management

Task 1.1 Management and provision of general Central Radiocarbon Laboratory capacity and related data management at the CRL

The provision of CRL capacity and services was unproblematic in 2022. The application for partial retirement of a long-standing CRL laboratory technician was approved so that this technician will receive reduced payments in 2022 and 2023 with full working hours. The retained remuneration will then be paid to the employee in the passive phase of 2024 and 2025 when no active working hours will be performed. In 2022, a new technician was hired on a temporary basis for the PAUL project, who may take over the vacant ICOS technician position in the future.

In late 2022 we initiated the expansion of the automated database exchange between the CRL and the Curt-Engelhorn Centre for Archaeometry (CEZA) to integrate further additional metadata into the CRL database. CEZA performs the Accelerator Mass Spectrometer (AMS) ^{14}C analyses on the ICOS flask samples as a third-party provider. These additional metadata will allow for deeper analysis of the uncertainties during the AMS measurement process and, in some cases, also help to enhance the precision of the measurements themselves.

Deliverable 1: Provision of the Central Radiocarbon Laboratory capacity and the local database

Personnel task 1.1: 5.2 PM

Task 1.2 Reporting

The general report, including the financial and activity report 2021, has been submitted to the HO in Mar 2022, and the budget and work plan for 2022 were provided in September 2022 (Deliverable 2). CRL activity updates were reported at the General Assemblies in May and November 2022, as well as in online meetings with the SAB. For the planning of the coming 5-year financial phase from 2025-2029, the CRL has prepared a financial plan and two cost-cutting scenarios as requested by the GA.

Deliverable 2: CRL general report. The report includes the Annual Activity Report and the financial report, the Annual Work Plan and the Annual Budget for the following year and 5-years Financial Plan, it is based on templates provided by the HO, and it is submitted to the General Assembly and RI Committee.

Personnel task 1.2: 4.3 PM

Task 2. Data management / production

Task 2.1 Radiocarbon analysis of up to 1000 two-weekly integrated CO2 samples per year from the ICOS RI atmospheric station network

In 2022, 16 atmospheric ICOS class 1 stations provided integrated CO_2 samples to the ICOS CRL. Additionally, we analysed integrated samples from three ICOS class 2 stations Izana, Mace Head, Schauinsland and the ICOS CRL pilot station. Mace Head and Izana are key stations for determining the marine $^{14}CO_2$background concentration. In total, 415 European samples were analysed by low-level counting. In addition, we analysed 17 integrated $^{14}CO_2$ samples from the polar stations Neumayer (Antarctica) and Alert (Arctic) and the ATTO (Amazon Tall Tower Observatory) tower. The samples from the Arctic clean air station allow the comparison of different global measurement networks. In the course of the CORSO project, Alert flasks from the SCRIPPS observation network are now being analysed for $^{14}CO_2$ in order to investigate compatibility with the ICOS observations.

In 2022, an alternative sample preparation line for integrated samples was set up and tested. In this preparation line, CO_2 is aliquoted directly after extraction from the NaOH solution into break seals, which can then be converted into AMS targets by means of the extraction-and-graphitisation-line (EGL). The compatibility of the two alternative processing techniques is quantified on the basis of 50 samples that are run simultaneously through both preparation lines.

Deliverable 3: Continuous reporting of integrated $^{14}CO_2$ analysis L1 data for all atmospheric class-1 stations

Deliverable 4: 1 Revision of L1 integrated $^{14}CO_2$ analysis data to L2 data for each atmospheric data release

Personnel task 2.1: 23.6 PM

Task 2.2 Radiocarbon analysis of CO2 from up to 1000 flask samples per year

In 2022, the number of ICOS flask analyses increased to 378 compared to 251 in the previous year. This is an increase of more than 50%, however, still less than what we would have expected to receive. It should also be said that for some stations, not all samples from the 2022 year have arrived yet. To increase the number of ICOS flasks selected for 14C analysis even further, the CRL, in collaboration with the FCL personnel, has selected additional ICOS flasks from winter 2022/2023 for 14C analysis.

Additional 64 samples of the flask analysis capacity have been devoted to the CRL pilot station and used to further develop sampling strategies and test new surrogate tracers for fossil fuel CO_2 (see Task 3.3).

In the course of the PAUL project, 103 further flasks were processed and analysed for ^{14}C. The labour required for this as well as the costs for consumables and AMS analysis, are fully covered by PAUL project funds.

The data transfer of the ^{14}C flask results to the FCL is operational. However, no ^{14}C flask results were transferred in 2022 as the CRL team is working on integrating an additional quality control step which includes automatic quantification of the added uncertainty. In this additional quality control step, the ^{12}C currents of the samples are compared with those of the calibration standards. If they differ too much from each other, an additional uncertainty has to be applied to the ^{14}C result of the sample. The automatic integration of this QC step required a considerable extension of the data exchange between the CRL and the Curt-Engelhorn Centre for Archaeometry (CEZA), which operates the accelerator mass spectrometer (AMS). The evaluation of all ^{14}C flasks analysed so far showed that for only about 5 % of the samples, the overall uncertainty of the ^{14}C results is significantly increased. Nevertheless, the CRL management has decided not to release any ^{14}C flask results until this automatic quality control step is firmly implemented, which will be the case in the summer of 2023.

***Deliverables 5&6*:** Continuous reporting of flask ^{14}C results is on hold and awaits final implementation of 12C current-related additional uncertainty. Planned to be operational in the summer of 2023.

Personnel task 2.2: 10.3 PM

Task 3. Network coordination, training and development

Task 3.1 Interaction with station PIs

The CRL scientists participated in the virtual ICOS Atmosphere MSA meetings in March, May and December 2022. The $^{14}CO_2$ results from integrated sampling and the flask sampling had been presented to the MSA participants. There is a regular email exchange between the CRL and the stations concerning the supply of sample supply, spare parts, and other issues. The regular transfer of samples between the stations and the CRL works smoothly.

To increase the number of ICOS flasks selected for ^{14}C analysis, the CRL, in collaboration with the FCL person, has selected in total 66 additional ICOS flasks from winter 2022/2023 for ^{14}C analysis.

Deliverable 7:Meeting and continuous interaction with station PIs. Annual meeting and ongoing exchange with station PIs to discuss CRL-related issues (together with MSA)

Deliverable 8: Supporting PIs in the $^{14}CO_2$ flask sample selection.

Personnel task 3.1: 2.1 PM

Task 3.2 Production of integrated CO2 samplers

In 2022 three integrated CO_2 samplers were built for the new class 1 stations in Italy (Lampedusa, Potenza, and Monte Cimone).

Deliverable 9 $^{14}CO_2$ integrated sampler production. Production of 3 integrated samplers

Personnel task 3.2: 3.4 PM

Task 3.3 Operation of the ICOS Pilot station, development and evaluation of ffCO2 monitoring strategies

In 2022 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_2 measurements
- semi-continuous in-situ ^{222}Rn measurements
- flask sampling using the ICOS flask sampler
- integrated CO_2 sampling for $^{14}CO_2$ analysis

With the continuous operation and the transmission of the in-situ GHG data to the ATC, Deliverable 10 was partly fulfilled. As mentioned above, the data submission of the ^{14}C flask results from the CRL pilot station where withheld.

In 2022, Maier and co-workers wrote a review paper on the determination of regional $ffCO_2$ concentrations from $^{14}CO_2$ observations and quantifies the problems and uncertainties involved (Maier et al., 2023a). In addition, the investigation of CO as a proxy for $ffCO_2$ was completed at the Heidelberg pilot station. Fabian Maier has written two companion publications as part of his dissertation that are

ready for submission. The first publication (Maier et al., 2023b) deals with the bias-free calculation of CO-based $ffCO_2$ and shows this using the example of the CRL pilot station and the ICOS class 1 station OPE. The CO-based $ffCO_2$ estimates typically have a four times higher uncertainty compared to the ^{14}C-based $ffCO_2$ estimates. The second publication (Maier et al., 2023c) examines which $ffCO_2$ estimate, ^{14}C or CO-based, provides more information for inverse $ffCO_2$ modelling in the Rhine Valley. It shows that for the CRL pilot station, the continuous CO-based $ffCO_2$ estimate produces a significantly better agreement with the bottom-up emission expectations. Likewise, the emission reductions during the Corona lockdowns can be clearly derived from the data using the CO-based $ffCO_2$ time series. The fact that the CO-based $ffCO_2$ at the CRL pilot station yields significantly better inversion results is due to the combination of the heterogeneity of the fossil fuel sources in the catchment area of the pilot station and the fact that the atmospheric transport cannot be simulated accurately enough in the state-of-the-art WRF-STILT model applied in this study. Whether this result that CO-based $ffCO_2$ estimates are superior to ^{14}C-based estimates for inverse modelling purposes also applies to ICOS stations is to be investigated in the PhD by Max Gachivsky, who will test the CO-based vs the ^{14}C-based $ffCO_2$ estimates on the continental European scale (see Task 5).

In 2022 we assigned a master thesis that applies the methods and insights we found regarding the CO proxy to the NO_x measurements. Although the continuous NO_x time series suggest a similar methodology as for CO, there is a crucial difference. The CO/$ffCO_2$ ratio could be derived robustly and with low uncertainties from periods with reduced atmospheric mixing and resulting large excess signals for ΔCO and $\Delta ffCO_2$. For the NO_x proxy, this approach is questionable since periods with reduced atmospheric mixing (e.g. nocturnal situations) are associated with different NO_x air chemistry. This makes the transfer to different time periods difficult. The determination of the $NO_x/ffCO_2$ ratio from afternoon well-mixed situations involves the difficulty of deriving a robust ratio from small excess signals.

Deliverable 10: Operation of the CRL pilot station. Continuous operation of ICOS standard instrumentation at the CRL pilot station, provision of in-situ data to the ATC. The flask ^{14}C results are currently withheld see Task 2.2.

Personnel task 3.3: 8.5 PM

Task 4. Projects and international cooperation

The CRL is participating in the PAUL project coordinated by the ICOS ERIC and contributing to WP3. In 2022 the CRL, supported by a dedicated master's student, was operating the Relaxed Eddy Accumulation (REA) sampler in Zurich and was responsible for selecting suitable samples for subsequent analysis at the FCL and the CRL. The flask analysis costs, the consumables and a dedicated part-time technician in the CRL are provided by the PAUL project.

For the ATTO+ (Amazon Tall Tower Observatory, Coordinator MPI-BGC) project, funded by the German BMBF, the CRL analysed 8 integrated samples in 2022 The number of samples analysed is low because the samples were delivered relatively late from Brazil and the samples have to be timed into the ICOS sample flow. The ATTO+ project pays 250 €/sample plus OH costs. All results will be available to ICOS RI.

In 2022, CRL was successful in obtaining an EU-Horizon-funded grant for the CORSO (CO2MVS Research on Supplementary Observations) project coordinated by ECWMF. This project will analyse all regular ICOS flask samples from ten western European ICOS class 1 stations for $^{14}CO_2$ in the calendar year 2024. To be able to process this increased number of samples, a second graphitisation system for the CRL will be built in cooperation with ETH Zurich. The CORSO project funds the analysis of the additional samples, the development and construction of the new graphitisation system and an additional technician position for its operation.

The CRL completed the coordination and arrangements for a second international pure-CO_2 ICP in 2022. Within the framework of this ICP activity, all laboratories that contribute significantly to global atmospheric $^{14}CO_2$ background observations will make about 50 comparison measurements over a period of one year.

Deliverable 11: Report on Projects and International and extra-ICOS collaborations. It reports, in the context of the Annual activities report, the activities performed and the results obtained from the participation in research projects and other collaboration activities.

Personnel task 4: 0 PM

Task 5. Other activities

The CRL is leading an MSA Atmosphere working group established in 2022 on the refinement of the $^{14}CO_2$ Flask sampling strategy. The task of this working group is to develop a $^{14}CO_2$ sampling strategy which minimizes the effect of nuclear ^{14}C emissions in ICOS flasks.

Max Gachivsky, in cooperation with the MPI-BGC in Jena, is working on $ffCO_2$ modelling on European scales using the CarboScope TM3/STILT inversion system. The use of the ICOS Integral ^{14}C samples proves to be difficult since the transport errors of the applied models are large. We are currently trying to quantify the extent of the transport errors by using ^{222}Rn measurements. As a consequence of the studies by Maier et al., 2023b&c we are currently working on retaining a $\Delta CO/\Delta ffCO_2$ calibration for suitable ICOS class 1 stations in order to subsequently test the CO-based vs ^{14}C-based $ffCO_2$ approach on a continental scale.

In 2022 CRL participated in the following meetings, conferences or expert groups:

- Royal Society Meeting: Radiocarbon in the Anthropocene 2022
- ICOS science conference 2022
- Transcom meeting 2022
- GGMT meeting 2022
- Copernicus CO_2 Task Force

Personnel task 5: 6 PM

References:

Maier, F., Levin, I., Gachkivskyi, M., Rödenbeck, C. and Hammer, S.: Potential of 14C-based versus ΔCO-based ΔffCO2 observations to estimate urban ffCO2 emissions, 2023c, ready for submission

Maier, F., Levin, I. and Hammer, S.: Uncertainty of continuous ΔCO-based ΔffCO2 estimates derived from 14C flask and bottom-up ΔCO/ΔffCO2 ratios, 2023b, ready for submission

Maier, F., Levin, I., Gachkivskyi, M., Rödenbeck, C. and Hammer, S.: Estimating regional fossil-fuel CO_2 concentrations from $^{14}CO_2$ observations: Challenges and uncertainties. Phil. Trans. R. Soc. A, doi: 10.1098/rsta.2020.0568, 2023a, accepted.

Maier, F., Gerbig, C., Levin, I., Super, I., Marshall, J., & Hammer, S. (2022). Effects of point source emission heights in WRF–STILT: a step towards exploiting nocturnal observations in models. *Geoscientific Model Development*, *15*(13), 5391-5406.

Hua, Q., Turnbull, J. C., Santos, G. M., Rakowski, A. Z., Ancapichún, S., De Pol-Holz, R., ... & Turney, C. S. (2022). Atmospheric radiocarbon for the period 1950–2019. *Radiocarbon*, *64*(4), 723-745.

Flask and Calibration Laboratory (FCL)

Task 1. General management

Task 1.1 Management and provision of Flask and Calibration Laboratory capacity and related IT- and data management at of FCL

To secure the provision of FCL laboratory facilities the lenting contract for the lab and office space was re-newed in the Technology Center am Felsenkeller in March 2022 with a prolonged term until 31.12.2026. The long-lasting dispute with the landlord on correct service charge statements was settled.

To ensure the data management for the calibration measurements a software upgrade of the data processing software became necessary and was elaborated when one of the analyzers failed and needed to be replaced. The $^{14}CO_2$ data transfer from CAL-CRL to the ATC has been arranged via the CAL-FCL database after clarification and implementation of the procedure.

The FCL database was also expanded to include functionalities for tracking the results of the inspections of sample containers for the ICOS network. This allows to identify flasks that had been added to the ICOS flask pool before the introduction of standardized initial inspections to foresee them for this check. The status of complaints at the manufacturer about faulty sample containers can now also be tracked much easier thanks to the database support. The input of the inspection results to the database is mostly automated to reduce staff efforts.

Deliverable 1: Provision of the Flask and Calibration Laboratory capacity and the database

Task 1.2 Reporting

The general report including the financial and activity report 2021 has been submitted to the HO in Mar 2022, the budget and work plan for 2022 were provided in September 2022 (Deliverable 2). FCL activity updates were reported at the General Assemblies in May and November 2022 as well as in online-meetings with the SAB.

Deliverable 2: FCL general report. The general report includes the Annual Activity Report and the financial report, the Annual Work Plan and the Annual Budget for the following year and 5-years Financial Plan, it is based on templates provided by the HO and submitted to the DG, RICOM and GA.

Task 2. Data management / production

Task 2.1 Trace gas analysis (CO2, CH4, CO, N2O, SF6, H2) of flask samples for ICOS RI atmospheric monitoring.

The number of ICOS class 1 stations that have started their sampling programme has increased to 15. The number of ICOS station samples that have been analysed at FCL has been 2297 (Deliverable 3). The Flask data transfer routines to the ATC have been implemented, flask sampling and flask data files reported. This includes the re-submission of data that needed to be revised after calibration updates and further quality checks.

Deliverable 3. Flask Sample Trace Gas Analysis. Trace gas analysis of flask samples from atmospheric class 1 stations.

Task 2.2 Analysis of supplement parameters (CO2 stable isotopes and O2/N2 ratios)

The analysis of CO_2 stable isotopes and O_2/N_2 ratios in flask samples was performed by mass spectrometry (Deliverable 4).

In parallel, the measurement capacity expansion of CO_2 isotope measurements has been progressed by putting a new measurement set-up into operation. The aim is to increase sample throughput through automation to keep up with growing number of samples and ideally offer additional capacities for CO_2 isotope measurements of high pressure cylinder standard gases for ICOS stations. The fully automated interaction of the sample selection unit at the flask rack, the triple cold trap unit for freezing CO_2 from air samples and the measuring device has been implemented. This enables automated measurement and data processing also over night with fully standardised measurement routines and automatic data analysis and data storage. Performance tests and final process optimization of this new setup could not be concluded in 2022 and are being continued.

Deliverable 4. Flask Sample Isotope, O_2/N_2 Analysis. CO_2 stable isotope and O_2/N_2 ratio analysis of weekly flask samples from atmospheric class 1 stations

Task 2.3 Support to maintain ICOS network flasks fit for purpose (flask specification check, flask leak check, flask conditioning)

The intactness of ICOS flasks after complete sample analysis is controlled by a routine procedure of leak check and subsequent filling with a "transport" air before being re-sent to the stations. In the prototype apparatus of an automated helium leak test unit for this purpose the hardware was significantly improved, the software programmed, tested and optimized in terms of sample throughput with sufficiently reliable leak test results. The automated test apparatus was run in parallel with manual tests for an extended period of time to assess the leak check effectiveness. Regarding the number of correctly detected defective flasks the automated system proved to be superior to the manual checks. At the same time the share of flasks with incorrectly detected leaks was reduced continually. The automated procedure is now running routinely but it is still in trial operation mode as the length of an individual test is such that the current set-up does not yet provide the capacity needed for the ICOS flask throughput. Therefore, the potential of further leak test time optimization is further examined. If needed design changes of the prototype will be considered.

Task 2.4 Production of real air high pressure standard gases within specified composition ranges for the ICOS continuous-core parameters (CO2, CH4, CO, N2O)

Standard gas cylinders for ICOS stations were prepared as requested. A total of 98 reference gases were provided to 30 atmospheric stations or ICOS Atmosphere Central Facilities (Deliverable 6).

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 24 standards has been produced, calibrated and delivered to the OTC and ICOS ocean PIs (Deliverable 7). Another 18 cylinders were prepared to be available as exchange sets when needed.

Deliverable 5:Standard Production for Atmospheric Observations. Filling of high-pressure cylinders with real ambient air, depletion / spiking of relevant tracers to produce targeted composition of standard gas for CO2, CH4, CO, N2O atmospheric monitoring activities of ICOS RI.

Deliverable 6: Standard Production for Ocean Observations. Filling of high-pressure cylinders with real ambient air, depletion / spiking of CO2 to produce targeted composition of standard gas for CO2 monitoring activities of the ICOS Ocean Network.

Task 2.5 Calibration and re-calibration of above-mentioned standard gases every third year relative to the current WMO calibration scales at any one time

All standard gases produced in task 3 have been calibrated plus another 120 standard gases that were returned to FCL for re-calibration (Deliverables 7, 8). Seven Replacement Sets are made available for periods when stations return their standard gases for recalibration and re-calibrated regularly. (Deliverable 9).

Deliverable 7: Standard Calibration for Atmospheric Observations. Analysis of high pressure cylinder standard gases for ICOS continuous core parameter according to WMO compatibility target accuracy.

Deliverable 8: Standard Calibration for Ocean Observations. Analysis of high pressure cylinder standard gases for ICOS stations linked to NOAA-ESRL gravimetric standards.

Deliverable 9*:* Replacement Standard Provision. Provision of replacement calibration standards during periods when stations return individual standards for recalibration

Task 3. Network coordination, training and development

Task 3.1 Interaction with station PIs

The FCL scientists participated at the virtual ICOS Atmosphere MSA meetings in March, May and December 2022. The reports on FCL activities were put up for discussion. 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 mailing lists and named contact persons (Deliverable 11).

The intended flask sampler technical user workshop could not be organized due to COVID restrictions in 2022 but dates for these workshps were fixed at the December 2022 MSA (Milestone 2).

Deliverable 10: Meeting with station PIs. Annual meeting with station PIs to discuss CAL-related issues (as part of the MSA)

Task 3.2 Organisation of and participation in international QC activities to link ICOS to other global networks.

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 have been re-analysed and new samples were prepared. The WMO Round Robin 7 circuit 6 set has arrived at FCL, been analysed and data submitted to NOAA. Two additional sets of each six "Sausage"- flask samples have been prepared and distributed to the participating seven participating laboratories (Deliverable 11). Results of this latter exercise have been evaluated and presented at the *21st WMO Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Measurement Techniques (GGMT-2022)* and the *Metrology for Climate* Workshop by BIPM.

The QC report was updated and is made available on the FCL webpage considering the results from all internal and external QC activities conducted up to 2022 (Deliverable 12).

Deliverable 11: QC samples. Preparation, distribution to international partner laboratories and analysis of comparison samples for international quality control program (flasks, cylinders). Participation in global round robin exercises (e.g. WMO round robin).
Deliverable 12: QC Report. Performance report on QC activities.

Task 3.3 Flask sampler support, development and implementation of new flask sampler capabilities

Flask samplers are now in operation at 15 ICOS class 1 sites and the ICOS CRL Pilot Station. Flask sampler support has been offered to these stations and given remotely when needed in 2022. In addition, a team from FCL provided on-site flask sampler support at the high altitude station Jungfraujoch in Switzerland

where the sampling conditions are exceptionally demanding. Four more flask sampler units have been delivered to the ICOS network (ICOS Italy). A report has been given to the virtual MSA on 06.12.2022 (D. 13).

Deliverable 13. Report to MSA on new ICOS flask sampler developments.

Task 4. Projects and international cooperation

Within the PAUL project, FCL has facilitated to measure integrated CO2 fluxes by Eddy Covariance. To this end a sampling solution for fast switching between two different air sample sources has been developed, a respective device constructed, tested and brought successfully to operation at the ICOS Cities site in Zürich. 150 flask samples from the PAUL sampling campaign in Zurich have been analysed at FCL for CO_2 mole fractions and forwarded to the CRL for radiocarbon analysis. An evaluation of these data will be done at the CRL to quantify the share of fossil fuel-based CO_2 in the urban CO_2 fluxes.

Armin Jordan has regularly participated in online meetings of the CCQM - GAWG's (Consultative Committee for Amount of Substance - Gas Analysis Working Group's) Task Group on greenhouse gas scale comparisons. Discussions have been held between representatives from National Metrology Institutes (NMIs), the WMO Global Atmosphere Watch community and from other atmospheric observation networks to set-up a protocol for establishing calibration scale relationships with very low uncertainty. The preliminary results have been discussed at the "Metrology for Climate Action 2022" online workshop.

Deliverable 14: Report on Projects and International and extra-ICOS collaborations. It reports, in the context of the Annual activities report, the activities performed and the results obtained from the participation in research projects and other collaboration activities.

Task 5. Other activities

In 2022 FCL has performed the following PR and educational activities:

- Presentation of ICOS at a public event during the 25 anniversary of the Max-Planck-Institute for Biogeochemistry in Jena (June 2022)
- Lecture "Work of the Flask and Calibration Laboratory of the Integrated Carbon Observation System" with the "Schülerexpress" program for 11th class chemistry intensive course students (July 2022)
- Laboratory Presentation at the "Long Night of Science" in Jena (25.11.2022)

Atmosphere MSA

- **Three MSA atmosphere virtual meetings** were held in 2022 on March 23, May 19-20 and December 6-8. More than 50 participants attended the first meeting, more than 80 persons the meetings in May and December. The March meeting was devoted to the data review allowing a timely release of the Level-2 dataset in June 2022. The afternoon session had scientific presentations by the station PIs and the chairs of the Ecosystems and Oceanic domains. In the May and December meetings the activity updates of the central facilities were provided by the Head Office, the Atmospheric Thematic Centre, the Carbon Portal and the Calibration Laboratories. Sessions were mainly about technological advances and related discussions (i.e. presentation of new GHG analysers and assessment of analytical performances, implementation of flask sampling data in the ICOS atmosphere data chain, new tool developed by ATC to monitor the data quality, use of flask sampling data as QC for continuous GHG measurements…). Additionally, incoming European calls (Horizon Europe) were presented and related information shared with the MSA community. Specific sessions were dedicated to the joint data review of the ICOS atmosphere data recorded since the previous MSA meeting but using a new workflow (see below).
- A **new data review process** was proposed and discussed within the MSA: Starting from 2022, data are pre-reviewed within sub-group of sites and only specific issues are discussed within the MSA

plenary. Sub-groups are leaded by voluntary chairs among the site PIs. A set of common diagnostics/metrics have been defined to review the data in a consistent way between the sub-groups.

- Besides the already existing working groups (i.e. quality managements, spiked detection), **new working groups** have been activated for the operation of tall towers, the refinements of $^{14}CO_2$ sampling strategy, the refinement of N_2O measurement guidelines, the operation of ICOS flask sampler and use of flask sampling data, the definition of new procedures for the ICOS atmosphere data review. Working groups are participated by station PIs and representatives from the Central Facilities and the Carbon Portal.
- To foster the **cross-domain interactions**, the MSA chairs participated to the meeting of the other domains and provided overview of their MSA organization, activities and caveats.
- A new dashboard for the monitoring of the overall quality of the ICOS ATM observations is available (https://icos-atc.lsce.ipsl.fr/map)
- Release of level-2 data of 36 atmospheric stations (90 vertical levels) https://doi.org/10.18160/KCYX-HA35
- 3 new atmospheric sites got the ICOS label (Ridge Hill Tower RGL – United Kingdom; Schauinsland SSL – Germany; Station Nord SNO – Denmark): up to now 36 atmospheric sites have been labelled.
- By sharing and revising historical data, the station PIs contributed to the creation of a Level-3 data product created by ATC and CP intended to represent the European contribution to the NOAA-GML Observation Package (ObsPack) Data Products (https://doi.org/10.18160/1RE0-2GKH).
- The ICOS Atmosphere MSA data significantly contributed to the investigations related to the methane release after the incident of the "North Stream" gas line in the Baltic Sea (https://www.icos-cp.eu/event/1221)
- The ICOS Atmosphere MSA contributed to the WMO International Greenhouse Gas Monitoring symposium (Geneve, 30 January – 1 February 2023) by submitting an abstract related to the presentation of the ICOS Atmosphere network as a "blueprint" for an operational in-situ network for high-precision atmospheric greenhouse gas observations.
- Participation and representation of ICOS from MSA members at the 21th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Measurement Techniques (GGMT-2022)
- MSA members participated to capacity building via the GAWTec course on GHG in March 2022 presenting ICOS activities as well as at the 6th WCC-SF6 Training and Education Course (online, Korea)
- Documentation of operational procedures is continuously discussed and elaborated at the MSA meetings.

Ecosystem MSA

- The Spring ECO MSA meeting took place as a virtual meeting 11-13 May 2022. There were over 60 participants. Previous to this, a questionnaire had been circulated to the whole ECO MSA to identify the needs and challenges of our network, as well as the most important scientific topics for collaboration. During the meeting we discussed a.o. the scientific exploitation of our ecosystem netwerk, interaction with other RI's, ideas for joint Horizon Europe proposals, interaction with the

ETC (eg. Protocol updates), labelling issues, availability of the data products, new variables (eg. PPFD_bc).

- The Fall ECO MSA meeting took place as a virtual meeting 7, 9 & 14 November 2022. There were about 50 participants. We discussed a.o. how to proceed in harmonizing ICOS data with historical data, updates of the protocols, the 5-year plan for the GA, station synergies, Horizon calls, WMO GHG activities and scitific issues.
- We created working groups to foster collaborations themed around measured ICOS variables.
- Many ECO MSA members were actively involved in the ICOS Science Conference.
- The ECO MSA contributed to the WMO International Greenhouse Gas Monitoring symposium by attending and presenting a poster.
- The ECO MSA is involveld in the organisation of the upcoming Fluxnet meeting in Europe.

Ocean MSA

- 3 Marine stations were stations labelled during 2022
- We have organized 3 MSA meetings (2 in-person and 1 remote). Utrecht 34 participants, Paris 28 participants, remote around 30 participants. The MSA meeting in November was connected to the Quince-training workshop in Paris.
- Strong participation of the Ocean Community in preparation of Fluxes
- Preparation and presentation of a poster at the WMO Greenhouse Gas Symposium in Geneve
- Strong presence of Ocean PIs in the ICOS Science Conference (Sep 2022)
- Strong presence of ICOS PIs in GCB 2021 (published in 2022)
- The annual station ringaround was completed in February/March 2022

ICOS National Networks

Belgium

Highlights

2022 Will be remembered as the year of "(re-)connecting": for the first time in two years it was again possible to meet each other in real life. Online meetings during the Corona pandemic enabled us to keep in touch with each other. Nonetheless, real life events in 2022 proved the importance of meeting each other in person in order to brainstorm freely about science and get to know each other in a more casual setting. For everyone who joined the ICOS Network recently, these events were a great opportunity to finally connect with people who they had – before this year - only met on a screen. For all those who were part of ICOS for a longer period, reconnecting with colleague's from inside and outside the National Network provided an energy boost. Full of (renewed) energy and with tons of new inspiration we are looking forward to conduct important climate science and impact climate policy in 2023.

Changes in station network

Two stations from the ICOS-Belgium Network received their ICOS Label during the GA of 2022. The grassland station in **Dorinne** operated by Liège University is now labelled as a **Class 2** measuring site. The **Yangambi station**, operated by Ghent University and the Research Center of Yangambi, is now the first official **associated ICOS site** in the Congo Basin. In 2022, no new ICOS sites were started and no existing sites were closed.

Co-operation with other RIs

The co-location of sites information is in Annex 4.

Czech Republic

Highlights

The 16th session of the ICOS ERIC General Assembly hosted by ICOS CZ in Prague from 17th to 18th May 2022. Two of new stations are the Experimental ecological workplace Bílý Kříž and the Ecosystem station Lanžhot labelled at 16th GA session in May 2022. All Czech stations are labelled since 16th GA.

Changes in the station network

Two of new stations are the Experimental ecological workplace Bílý Kříž and the Ecosystem station Lanžhot labelled at 16th GA session in May 2022. All Czech stations are labelled since 16th GA.

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.

Denmark

Highlights

A close joint effort between the Danish group succeeded to get the ecosystem station in North East Greenland labelled as a class 2 site. Spectacular and a big burden got lifted from our shoulders.

Changes in station network

Zackenberg Fen as Class 2, Zackenberg Heath as associated site, Sorø as Class 1

Co-operation with other Ris

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

Finland

Highlights

High visibility and interest towards Utö station and data, and FMI expertise in September due to the Nord Stream gas pipe leakage

Long-term CO2 flux paper from Hyytiälä SMEAR II ECO station, disentangling the reasons for an increasing GPP trend in the pine forest was published (Launiainen et al. 2022)

Changes in station network

No new stations completing labelling in GA meetings of 2022

Finland originally suggested four new stations and one upgrade for ICOS HO in June 2022, but due to some funding complications, the final list, established in February 2023, included only three new stations:

- MS Silja Serenade (FMI, OCEAN Class 2)
- Tvärminne (UHEL, ECO Associate and OCEAN Class 2)
- Oulanka (UOulu, ECO associate)

France

Highlights

Ecosystem + Atmosphere network: Major summer drought in the south of Europe. Ongoing ecosystem station study on summer drought by Emilie Joetzjer. and atmosphere signal by Michel Ramonet

ETC soil Level 2 data are starting to come out.

Nord stream: First analysis of CH4 emissions from the Nordstream gas pipeline explosions that took place end of September 2022. Detection of the atmospheric signal at the ICOS stations in the North of the Europe; first quantification of emissions by atmospheric inverse method

Changes in station network

Stations completing labelling in GA meetings of 2022: Ecosystem stations 1C1 and 3 C2 FR-Hes, FR-Lus, FR-Fbn, FR-LQu

Co-operation with other Ris

- OBS4CLIM: As part of the national OBS4CLIM project, several actions have been initiated in collaboration with ACTRIS-Fr and IAGOS-Fr. The first development in connection with ACTRIS consists of integrating GHG (CO2, CH4) and air quality (NOx, PM, CO, BC, ...) sensors into a common system, called ATMOBOX, intended to be deployed for various applications including monitoring the atmospheric composition in Paris (ICOS-Cities). A second development undertaken this year consists of the construction of 5 enclosures for the automation of measurements of total columns of CO2, CH4, CO (EM27), in tropical sites collocated with measurements of aerosol content (AERONET/ACTRIS). Finally, a study is initiated for the development of a CO2/CH4 sensor intended to be deployed on board TGVs, and in the longer term commercial aircraft (IAGOS).

- ICOS-CITIES: Within the framework of ICOS-Cities we are developing collaborations with ACTRIS, with the aim of measuring atmospheric tracers (CO, NOx, BC, VOCs), or dynamic properties (boundary layer height, wind profiles), co-located at the sites measuring CO2 in the Paris region.
- ENVRI FAIR: EU project ending June 2023; contribution to the FAIR atmospheric demonstrator including a satellite collocation tool that will be shocase at the ENVRI week end of January 2023.

Germany

Highlights

With the "kick-off" meeting in October 2022, the German Integrated Greenhouse Gas Monitoring System (ITMS) which heavily builds on ICOS data was started. ITMS is a research project funded by the Federal Ministry of Education and Research (BMBF) with envisioned three consecutive project-phases starting with set-up and leading to operational services, combining existing observations from ICOS, IAGOS and satellites, know-how on flux processes, distributions and their modelling, and transport processes from the DWD's (German Meteorological Service) ICON model. The envisioned inversion scheme shall provide high level GHG flux products for Germany to monitor changes in surface processes and control success of mitigation measures. In the end, an operational data assimilation and inversion scheme shall continuously work at DWD and provide services based on, among others, ICOS data and ICOS knowledge.

Oceanic pCO2 (ICOS) combined with full suite of biogeochemistry measurements in the Antarctic during Polarstern PS129

After repeating droughts in 4 out of 5 years since 2018 the forest site DE-Tha had the lowest net annual CO2 sink in 2022 since start of the EC measurements in 1996. It was 251 gC m-2 a-1 only (mean: 418 gC m-2 a-1, max: 560 gC m-2 a-1 (2017)).

Forest site DE-Tha will be a test site for joint EC and sap flow measurements regarding an enhancement option for the forest level II monitoring.

The Saxonian minister of energy, climate protection, environment and agriculture Wolfram Günther visited the ICOS site Tharandt in November 2022 to be aware about the ongoing monitoring and main findings regarding the long-term C budgets of terrestrial ecosystems in Saxony. This meeting clearly showed the great significance of such long-term monitoring for climate research and quantitative assessment of CO2 sinks regarding the goal of C neutrality.

Labelling of station DE-SOOP-Atlantic Sail

New format of Annual ICOS Germany Meeting: all domains centred their presentations around focal topics. The Atmosphere Domain highlighted novel findings in methane research including studies on the isotopic signature. The Ocean Domain presented examples of successful data integration with other infrastructures. Both Atmosphere and Ocean contributed to timely analyses and visualizations of the Nord Stream pipeline leaks. The Ecosystem Domain focussed on carbon balances at agricultural sites, i.e. crop sites and grasslands, with presentations highlighting the value of long-term observations and the importance of proper accounting and including of lateral carbon fluxes from harvest and fertilization.

Changes in station network

Stations completing labelling in GA meetings of 2022

- Class 1 Ocean Station Atlantic Sail (DE-SOOP Atlantic Sail).
  Responsible institution: GEOMAR - Helmholtz Centre for Ocean Research Kiel;
  Station PI: Tobias Steinhoff
- Class 2 Atmosphere Station Schauinsland (SSL).
  Responsible institution: German Environment Agency - Umweltbundesamt (UBA);
  Station PI: Frank Meinhardt
- Associated Ecosystem Station Hartheim (DE-Har)
  Responsible institution: University of Freiburg; Station PI: Andreas Christen
- Associated Ecosystem Station Mooseurach (DE-Msr)
  Responsible institution: Weihenstephan-Triesdorf University of Applied Sciences (HSWT);
  Station PI: Matthias Drösler
- Associated Ecosystem Station Wüstebach (DE-RuW)
  Responsible institution: Research Centre Jülich (FZJ); Station PI: Marius Schmidt
- Associated Ecosystem Station Berlin-Rothenburgstrasse (DE-BeR)
  Responsible institution: Technische Universität Berlin; Station PI: Fred Meier

Co-operation with other RIs

- Participation of GEOMAR with station DE-SOOP-Atlantic Sail in the EU proposal GEORGE (NEXT **GE**NERATION MULTIPLATFORM **O**CEAN OBSE**R**VIN**G** T**E**CHNOLOGIES FOR RESEARCH INFRASTRUCTURES)
- MOSES (HGF) platforms deployed at CVOO for field demonstration missions
- MOSAiC project (Multidisciplinary drifting Observatory for the Study of Arctic Climate): international, interdisciplinary Arctic scientific expedition drift in the central Arctic
- Cooperation with SAEON (South African Ecological Observation Network), student exchange, joint papers, concept for tower operation
- New project "Process-based quantification of CO_2 fluxes of differently structured forest ecosystems at different spatial scales" funded by FNR (FKZ: 2218WK57A4) is hosted at ICOS Station DE-Kie.
- Joint use of ICOS stations in the project "Transpiration of forest trees as a future ecophysiological sign of life for forest environmental monitoring" funded by FNR (FKZ: 2220WK83A4).
- Ecosystem forest stations as ICP Forests Level II sites
- Cooperation with ACRI-ST and Ground-Based Observations for Validation (GBOV) of Copernicus Global Land Products - exchange of measurements and analysis results
- Aerosol Robotic Network (AERONET), Nasa Goddard Space Flight Center - exchange of measurements and analysis results

Hungary

Highlights

Hungary officially joined ICOS on 1 January 2022

Legal formation of the ICOS Hungary consortium

Refurbishing of Hegyhátsál tall tower atmospheric monitoring station (HUN)

Changes in station network

Labelling process of HUN atmospheric monitoring station was started. Refurbishing of Hegyhátsál tall tower atmospheric monitoring station (HUN).

Co-operation with other RIs

Atmosphere monitoring station HUN also provides flask air samples for NOAA Cooperative Global Air Sampling Network

Italy

Highlights

The Italian network organized and attended "Mission Carbon neutrality: role, status and perspectives of environmental observations", the first National Conference, held in Rome during 27th and 28th of September 2022. The event reunited almost 70 studies presentations, over 50 research institutions and almost 150 participants, including representatives from startups, companies and different stakeholders. The event gathered Italian scientific community whose work revolves around data collection and interpretation, emissions and absorption of greenhouse gases. The first national conference of ICOS Italy led to a broad and multidisciplinary discussion that highlighted knowledge, opportunities and upcoming challenges for the role of research in this area on both national and international extend. The presence of other RIs was particularly relevant, such as ACTRIS and LTER (https://www.icos-italy.it/2022/09/la-scienza-italiana-allavanguardia-sulla-via-della-neutralita-climatica-2/)

ICOS Italy stations of Plateau Rosa (IT-PRS) and Monte Cimone (IT-Cmn) were presented during a national television broadcast "Science Places" (https://www.raiplay.it/video/2022/12/I-luoghi-della-scienza-pt2-La-ricerca-in-montagna-8f699ad1-7a8f-4a5a-8717-5fa31081f41c.html) (https://www.raiplay.it/video/2022/12/I-luoghi-della-scienza-pt3-Clima-e-biodiversita-in-montagna-5d5eefc8-1e60-4b8f-966c-6334faf5865b.html).

The North Stream 2 leak events received a broad coverage by the national media and social networks with high visibility for ICOS: the ICOS national network staff provided interview and notes about the event and the related impacts.

On December 2022, the kick-off meeting of the ITINERIS project was held in Rome and the CNR HQs. ITINERIS is a cross environmental RIs project coordinated by CNR, with the aim to connect the participating RIs and their data flows and to strengthen the collaboration at EU level.

A virtual meeting of the ATM component of the Italian national network was organised on 14/11/2022. This was the first step towards a more active and effective collaborations among the different Institutions (ENEA, RSE SpA, CNR-IMAA, CNR-ISAC) which manage the ATM sites in Italy. During the meeting a slot was devoted to the presentation of the measurement sites, followed by a broad discussion about technical issues and scientific topics to be jointly investigated.

During 2022 the Lampedusa Climate Observatory completed 25 years of activity. A national workshop with national representatived from ICOS, ACTRIS, and EMSO, took place in Rome on 6 December, 2022. About 50 people attended the workshop on site, and about 100 remotely. (https://www.enea.it/it/seguici/events/lampedusa/save-the-date-progetto-es-pa-e-contributo-dell2019osservatorio-climatico-enea-di-lampedusa-allo-sviluppo-sostenibile-sul-territorio-25-anni-di-ricerche-sul-clima).

As a stepping-stone to the National Conference, the Italian network organized an online webinar last year, in November 2021, entitled "After COP26. Science, challenge and prospective for the greenhouse monitoring". The event was attended by over 450 participants. (https://www.icos-italy.it/2021/11/gas-serra-e-cambiamenti-climatici-la-ricerca-italiana-e-pronta/)

Changes in station network

Stations completing labelling in GA meetings of 2022

- Associated Ecosystem Station Nivolet (IT-Niv) Country: Italy;
  Responsible institution: National Research Council of Italy (CNR) – Institute of Geosciences and Earth Resources (IGG); Station PI: Antonello Provenzale.
- FOS Ocean Station Miramare (IT-Mambo1);
  Responsible institution: OGS; Station PI: Michele Giani
- FOS Ocean Station IT-FOS-W1M3A (IT-W1M)
  Responsible institution: National Research Council of Italy (CNR) – Institute for the Study of Anthropic Impact and Sustainability in the Marine Environment (IAS); Station PI: Roberto Bozzano.
- Class 2 Ecosystem Monte Bondone (IT-MBo)
  Responsible institution: Fondazione Edmund Mach; Station PI: Damiano Gianelle

Co-operation with other RIs

A cross environmental RIs project (ITINERIS - Italian Integrated Environmental Research Infrastructures System) coordinated by CNR have been funded with a total budget of 150Meuro and 22 RIs involved. Specific resources to all the ICOS components for equipment, training and services development are foreseen. The project has the aim to connect the participating RIs and their data flows and will strength also the collaboration at EU level. On December 2022, the kick-off meeting of the ITINERIS project was held in Rome.

Netherlands

Highlights

ICOS Science Conference, Transcom, and GGMT2022: In late September 2022 the Dutch ICOS community hosted the worldwide greenhouse gas community in these three events, co-organized by ICOS ERIC, University Utrecht, and Wageningen University. Hundreds of participants were present at each event, plus many more profiting from the very professional remote attendance facilitated, and online services. Based on reactions afterwards each of these events was a resounding success, contributing to ICOS' goal to unite and service the global experimental and modeling communities.

Finances: The Dutch ministry of Economic Affairs and Climate has agreed to cover the Dutch ICOS fees for the 2nd (and subsequent) commitment periods. This allowed the Netherlands to pay their fees for 2022, and our dues from previous years.

Carbon Portal: The Dutch contribution to the Carbon Portal in 2022 supported the release of a new near real-time high-resolution flux product, CarbonTracker Europe-HR. It is available now as a monthly updated product at the CP, and documented in a publication (vanderWoude et al., 2022). The Dutch CP team moreover supported the Global Carbon Project in archiving datasets, including gridded global fluxes from seven inverse modeling systems that were used in Friedlingstein et al., (2022). Collaboration

and a research visit from Ida Storm (CP Lund) led to a new publication on the ICOS observing network and its view of the European flux landscape (Storm et al., 2022). Finally, a new initiative on documenting the 2022 summer drought in Europe was supported from Wageningen, leading the community that produces and analyzes the associated ICOS data.

Cabauw: As of September 2021 the Cabauw GHG data (CO2/CH4/N2O/CO) for four levels measured from buffer volumes as well as continuous GHG data (CO2/CH4) of the 207m level are flowing in the ICOS ATC database together with diagnostic data. In addition Radon data from 207 en 27m is sent automatically to and processed at ICOS ATC. In addition air samples are taken also every other day, one day shifted from the halocarbon sampling, for ICOS class-1 station quality control to Jena with a selected subset of these air samples being redirected to Heidelberg for ffCO2 analysis in addition to the biweekly continuous ffCO2 samples with the ICOS ffCO2 sampler. Furthermore work is in progress to upgrade the Spectronus for renewed measurements. In 2022 all level inlet lines have been moved from NW to SE of the tower to prevent contamination of air from inside the tower. The new year 2023 is starting well though with the one of the two broken Picarros (G2301) repaired. ICOS class-1 station labelling was planned for spring 2022 but due to non-available meteo data of the Cabauw tower, this has been postponed until spring 2023.

Loobos: In May 2022, an observation campaign was held to measure CO2, 18O, 17O, and COS uptake and release on different scales ranging from leaf level via ecosystem level to atmospheric scales. But 2022 was also the year of much new installations in Loobos: the eddy covariance system was finalised and the data are now sent to the ICOS-CP automatically. A profile system of temperature and wind speed and direction has been installed (5 levels), and together with the meteo data (radiation, temperature, RH, pressure at the top of the tower) these data are also sent to the ICOS-CP daily. Soil thermometers, soil moisture sensors, soil heat flux sensors have been installed, as well as a profile system for CO2 and H2O concentrations (11 levels). The ICOS-ETC class 2 label is scheduled for April 2023.

Lutjewad: As a class-2 station, Lutjewad continued to provide high quality near real time greenhouse data to the ICOS ATC/ICOS CP, including the period when natural gas leaks from the Nord Stream pipeline occurred. Furthermore, we have tested a portable LICOR N2O analyzer at Lutjewad, and made an attempt to fly the N2O analyzer on the SkyArrow airplane, and in a van while driving in the city of Groningen. Moreover, three successful SkyArrow flights were made using the newly developed active AirCore system for greenhouse gases, but also for COS. And in an effort to address the energy crisis, the energy consumption at the Lutjewad has been reduced, and the effort is still ongoing.

Changes in station network

None

Co-operation with other RIs

The newly starting ACTRIS RI will closely collaborate with ICOS in the Netherlands, with at least the Cabauw tower serving both programs.

Other than the ICOS related work at Loobos, partner UU has installed sensors to measure VOC concentrations and is now testing if fluxes can be obtained. Partner TUDelft has installed a DTS system to measure temperatures along the tower in high resolution and is testing the results. Non-Ruisdael partner RIVM is considering installing NH3 flux measurement sensors.

At Cabauw, from March 2021 onwards air samples are taken every other day for halocarbon analysis at Bristol university and simultaneously the Medusa system of EMPA has been measuring halocarbons continuously from 207m between December 2021 until July 2022.

Started in 2019, the Dutch National Research Programme on Greenhouse Gases in Peatlands (NOBV) has been building up an increasing number of GHG exchange monitoring sites on peat soils, mostly managed and some natural, aimed at building a monitoring network as well as a system to validate mitigation measures. So far 12 locations have been equipped with eddy covariance, one of which according to ICOS standards. These and other sites also run automated chamber measurements and a host of other soil observations. On top of this, almost weekly Skyarrow EC flux flights are carried out in three peat regions of the Netherlands.

Norway

Highlights

26th September 2022 saw the sabotage of the Nord Stream pipeline sabotage and subsequent release of methane to the atmosphere. Scientists at NILU, with previous experience from events such as the Eyjafjallajökull eruption and the Fukushima nuclear disaster, were able to swiftly perform atmospheric transport (FLEXPART) simulations of the leaks only a few hours after the leak had occurred. The simulation was compared with the near real-time ATC data from the ICOS Carbon Portal for Birkenes, Hyltemossa and other ICOS atmospheric sites, as soon as it was released, to produce estimates of the magnitude of the leak. NILU scientists then had contact with several media organisations, nationally and internationally, where the role of ICOS was emphasised. ICOS Norway thus played a key role in helping to ensure visibility of the wider network and creating the largest ever media story for ICOS. Subsequently, work is ongoing to use data from the event to refine leak estimates, and as a test-case for atmospheric transport and inversion models (since the location of the leak is well defined). The Nord stream leaks, while only transient, were likely the largest ever point source methane emission to the atmosphere.

Changes in station network

None

Co-operation with other RIs

The Norwegian atmospheric sites Zeppelin (ICOS class 1) and Birkenes (ICOS class 2) are both part of the ACTRIS network. In addition, the Zeppelin Observatory is a key station in many research infrastructures including the European Monitoring and Evaluation Programme (EMEP); the Arctic Monitoring and Assessment Programme (AMAP); the Global Atmosphere Watch (GAW); and the Advanced Global Atmospheric Gases Experiment (AGAGE) network.

Spain

Highlights

In 2022, ICOS-Spain has incorporated the El Arenosillo atmospheric station. In addition, different internal meetings took place with the aim of incorporating two new station in 2023: the ESTOC oceanic station and the Majadas de Tiétar associated ecosystem station. Therefore, the process of consolidation of the national network continues. ICOS-Spain and the Ministry of Science and Innovation actively

collaborated with the ICOS Head Office to organize the ICOS General Assembly in Madrid (22-23 November 2022).

The Spanish atmospheric stations, Izaña and El Arenosillo, have collaborated with the ICOS communication team by helping them to compile audiovisual material and interviews on the activities of these stations to disseminate the ICOS scientific activity to the society.

Finally, Spain participates in the ICOS cities (PAUL) project through the greenhouse gas monitoring network of the metropolitan area of Barcelona city within the project URBAG (Integrated System Analysis of Urban Vegetation and Agriculture).

Changes in station network

Izaña Atmospheric Station

- Since February, daily measurements of the Picarro and LGR instruments, as well as auxiliary data (pressure, humidity, temperature, etc.) are sent to the ATC.
- The first calibration of the Picarro and LGR instruments with the ICOS standards was done in November.

El Arenosillo Atmospheric station

- Jose A. Adame, group leader of trace gases at El Arenosillo station was confirmed as PI at El Arenosillo ICOS atmospheric station.
- In 2022 El Arenosillo atmospheric station class 2 started the observations in the tall tower of 100 m and its labelling processes.
- El Arenosillo atmospheric station started its labelling processes and on 8 August 2022 the step 1 was approved.

CanOA VOS Oceanic station

- During the year 2022, all sensors used in the CanOA VOS line oceanic station Class 1 were sent for calibration and updated to the factories, and were again included in the VOS line (the ship changed the name from RENATE P to JONA SOPHIE) in September 2022. Currently, the observations are being recorded to reach station labelling 2.

Co-operation with other RIs

Izaña atmospheric station 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)
- NOASS/ESRL/GMD CCGG Cooperative Air Sampling Network
- 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

- EUBREWNET (European Brewer Network)
- Carbon Tracker
- SDS-WAS WMO Sand and Dust Storm Warning, Advisory and Assessment System

El Arenosillo atmospheric station is part of the following research networks:

- Actris (AEROSOLS, CLOUDS, AND TRACE GASES RESEARCH INFRASTRUCTURE)
- WMO-GAW (Global Atmospheric Watch)
- AERONET (AErosol RObotic NETwork)
- MPLNET (Micropulse Lidar NETwork)
- WRC (World Radiation Center)
- WDCA (World Data Center of Aerosols)
- NOAA-ESARL Collaborative Aerosol Network

Canoa VOS oceanic station is part of the following research networks:

- GOA-ON (Global Ocean Acidification Observing Network)
- SOCAT (Surface Ocean CO2 Atlas)

Sweden

Highlights

High methane concentrations due to pipeline leakage observed at several Swedish stations (HTM, NOR, but also SE-Myc and SVB)

Norunda forest got logged and turned from a >100year old standing needle leafed forest into a clear cut site.

Changes in station network

Class 2 Ecosystem station Abisko-Stordalen palsa mire (SE-Sto) was certified in May 2022

Co-operation with other RIs

ACTRIS Sweden received funding as national RI and started in 2022. The permanent sites are strictly co-located with ICOS sites (SVB, NOR, HTM and ZEP). A mobile station will visit the different stations and will be available on users request at a later stage. Strategic discussions on how to best collaborate between the three Swedish national environmental RIs (www.fieldsites.se/ https://nordspec.nateko.lu.se; www.icos-sweden.se; https://www.actris.se) are ongoing.

Switzerland

Highlights

On 12 December 2022, the Swiss Parliament voted to apply for a change in Switzerland's status from ICOS observer to ICOS member. For ICOS Switzerland this means voting rights in the ICOS General Assembly, where it has so far only acted as Observer.

To celebrate 25 years of CO_2 flux measurements at our ICOS Class 1 Station Davos, a short film portrait was produced.

In summer 2022, the first urban CO_2 flux measurement system for ICOS Cities was installed in Zurich by ICOS-CH members from University of Basel and Empa, in collaboration with further project partners from ICOS-D and ICOS-FI.

Swiss Post issued a special stamp of Jungfraujoch to celebrate the go-ahead for the construction of a research station on Jungfraujoch 100 years ago.

Book release about the history of the research station Jungfraujoch: 'Das Jungfraujoch. Eine Geschichte der Hochalpinen Forschungsstation 1922-1952'.

EuChemS Historical Landmarks Award 2021 to Jungfraujoch station (a Symposium will be taking place in February 2023)**.**

Launch of the KADI (Knowledge and climate services from an African observation and Data research Infrastructure) project, coordinated by the ICOS Head Office; Swiss participation from Empa, MeteoSwiss and Agroscope.

Changes in station network

No changes in station network.

Co-operation with other RIs

Davos station is part of eLTER and the national networks Swiss FluxNet (Swiss network of active eddy-covariance flux sites), Long-term Forest Ecosystem Research (LWF), National Air Pollution Monitoring Network (NABEL), the biological drought and growth indicator network (TreeNet)

Jungfraujoch station is part of ACTRIS and the national networks National Air Pollution Monitoring Network (NABEL), CLIMGAS, SwissMetNet, Permafrost Monitoring Switzerland (PERMOS), Swiss Glacier Monitoring Network (GLAMOS)

United Kingdom

Highlights

The Ridge Hill atmospheric station completed the labelling process and became an official ICOS station in May 2022.

The JC231 research cruise to the PAP-SO site (1st-19th May 2022) to service moorings and undertake various deployments including a Met Office buoy with surface ocean biogeochemistry sensors.

Changes in station network

Stations completing labelling in GA meetings of 2022: Ridge Hill atmospheric monitoring station (May 2022)

Co-operation with other Ris

As well as becoming an official ICOS station in May 2022, Ridge Hill atmospheric monitoring station also continues to form part of the UK DECC network providing a link between the two networks. An exercise to compare the impact of the two different data processing chains is ongoing with initial results presented at the ICOS science conference in September 2022.

As part of the process of setting up ICOS regional sub-groups that will hold regular data review, Olivier Laurent from the ICOS ATC attended one of the UK DECC network data review meetings. The plan is to continue this knowledge exchange between the two networks.

Led Horizon Europe proposal GEORGE with EMSO and EuroARGO participating. Project now funded and coordinated by ICOS will bring new observing technologies to the ERICs and harmonise methods and procedures

Partner in a Doctoral Network proposal led by ICOS called CarboAdvance.

Annex 1

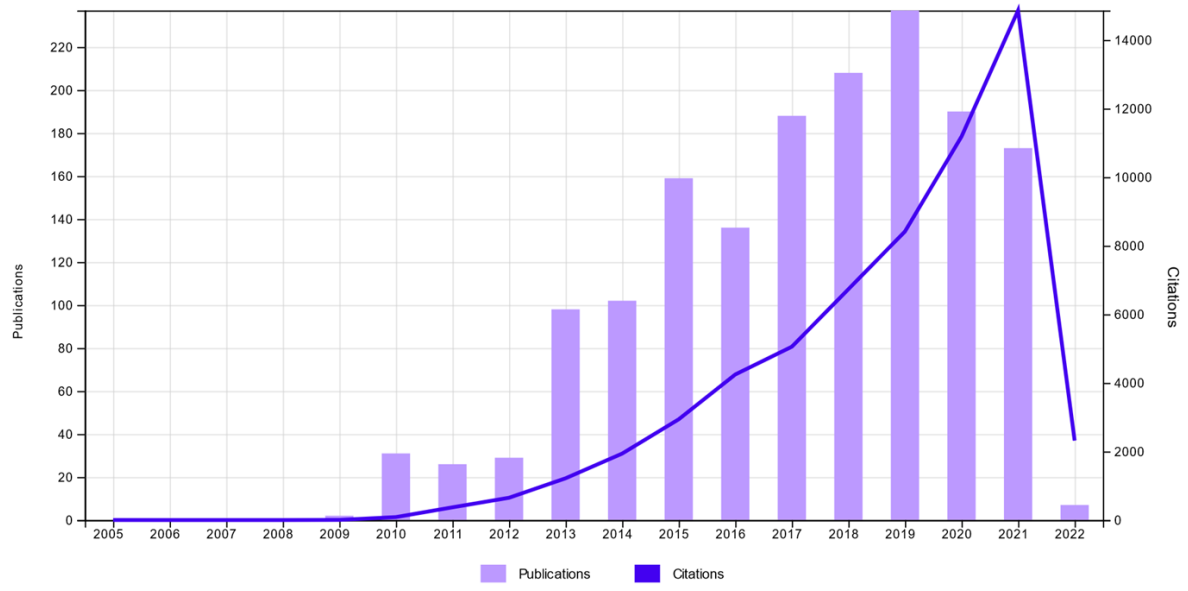
Data for the KPIs

ICOS publications and citations

Total of 1697 scientific articles are listed in the Carbon portal, 198 of which with year 2022.

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.



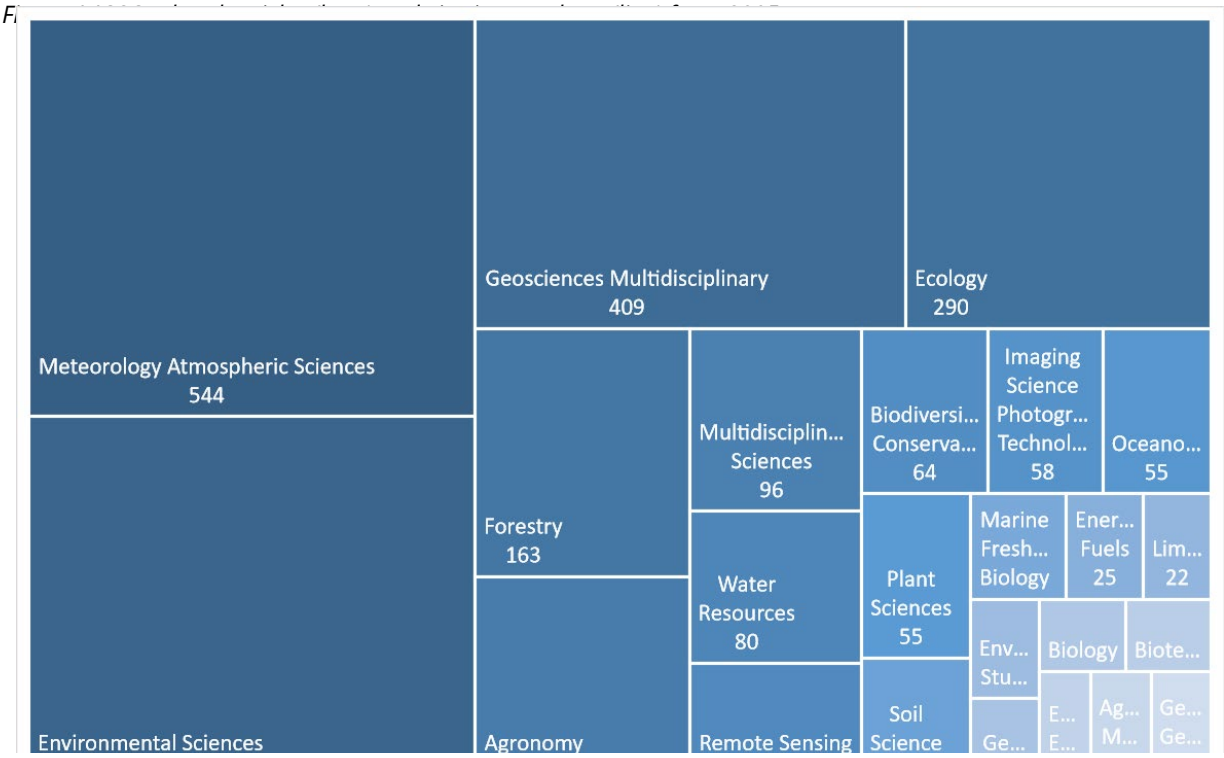


Figure 2 Topic categories of ICOS related articles

Facilitation of scientific initiatives (KPI 28)

1.	The '**Drought Initiative**' was a joint study undertaken within ICOS. It consisted of 17 studies published in a special issue of Philosophical Transactions B in September 2020. https://royalsocietypublishing.org/toc/rstb/375/1810
2.	**Warm winter 2019/2020 initiative** 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. https://www.icos-cp.eu/data-products/2G60-ZHAK
3.	**Horizon MSCA Doctoral Network proposal** (CarboAdvance) was re-submitted in November 2022, Coordinated by Ivan Mammarella (University of Helsinki). Proposal brought together scientific ideas, researchers and institutes across all ICOS domains.
4	**Nord stream pipeline gas leaks detection** by ICOS station network: Collaboration with modellers and observational scientists. Poster presented at UNFCCC Earth Information Day drawing attention to need of in situ data complementing satellites and models.
	Total for KPI 28: 4 scientific initiatives facilitated

Use of ICOS data in educational tools and activities (KPI 27)

Country	Educational or training activities
Belgium	Class of Excellence Francqui chair David Ellsworth for 40 young researchers including visit of Maasmechelen station. More information: International Collen-Francqui Chair David Ellsworth — Faculty of Bioscience Engineering — Ghent University (ugent.be)
Belgium **La Réunion**	ESA-NASA Training Course on Arctic Methane and Permafrost 2022
Belgium	Courses on Exchanges Ecosystems-Atmosphere (ULiège), Erasmus course (ULiège) and Bio-Climatology (ULiège)
Belgium	Conference on agriculture to fight climate change for the CETA-Hesbaye at Gembloux
Belgium	Leaf fall project M. Campioli (UAntwerpen)
Belgium	Requests from secondary education student for Ocean acidification data and info in the Belgian Coast (VLIZ)
Belgium	Ba. thesis of Y. Goossens (UAntwerpen)
Belgium	Ma. thesis of N. Pezzetti (ULiège), R. A. Djamko Ndiessidie (ULiège), K. Hoang Le Thien (ULiège), N. Vantyghem (ULiège), B. Montigny (ULiège), Tine Asnong (UGent, DRC), Renée Stockx (UGent, DRC), Ine Colman (UGent, DRC), Simon Huylebroeck (UAntwerpen), E. Goorden (UAntwerpen), Ma. Internship J. Van Mieghem (UAntwerpen), Noor Renquin (VLIZ)
Belgium	PhD of Q. Beauclaire (ULiège), L. Delhez (ULiège), F. Boland (ULiège), M. Delandmeter (ULiège), P. Belleville (ULiège), Ariza-Carricondo (ULiège), C. Dumont (ULiège), R. Daelman (UGent), Ariza Carricondo (UAntwerpen), M. Maleki (UAntwerpen)

Belgium (DRC)	Sensibilisation of local politicians, population and school children
Belgium	Lectures M. Bauters, P. Boeckx (UGent-wide sustainability lectures) and L. Lefevre
Belgium	Data contribution SOCAT and the 2022 Global Carbon Budget (VLIZ)
Belgium	Expedition Simon Stevin: Measuring biodiversity, pollution and pCO_2 along the Ostend/Antwerp trajectory
Belgium	Student site visits at: Lochristi (UGent students – course Functional Abiotic Interactions), Vielsalm (ULiège students)
Belgium	Class of Excellence Francqui chair David Ellsworth for 40 young researchers including visit of Maasmechelen station. more information: International Collen-Francqui Chair David Ellsworth — Faculty of Bioscience Engineering — Ghent University (ugent.be)
Czechia	Annually given in average 40 lectures 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 or policymakers (e.g. governments. regional authorities, municipalities.).
Czechia	4 dissertation theses, 1 master thesis
Denmark	NRT data used for a geography bachelor project – 3 Students
Denmark	MSc thesis in Geography on on GHG balance of the rewetted area in Skjern Meadows
Denmark	.Many other student and research projects unidentified
Finland	Eddy covariance intensive course 2.5.-6.5.2022 in Helsinki (27 participants)
Finland	Field course in Micrometeorology and Hydrology, Hyytiälä forest station, 28.8-2.9.2022, number of participants: 26 (ICOS data was used in the course)
Finland	Field course "Carbon dynamics of forest soils", Hyytiälä Field Station, 19-22 April 2022, Master's and PhD level, 7 participants
Finland	Internship of MSc student Péter Garamszegi (Wageningen University, The Netherlands) in Peatland and Soil Ecology Research Group, University of Eastern Finland, Finland. Supervisors in UEF: Eeva-Stiina Tuittila, Egle Köster and Elisa Männistö. (ICOS site FI-Sii).
Finland	Internship of MSc student Claudia Cagliardi, Italy, from January to June. MSc thesis utilizing CO2 EC flux data from Haltiala station (cropland) in Helsinki.
Finland	Three doctoral thesis: Männistö E., 2022. Emissions of methane and other biogenic volatile organic compounds from boreal peatlands. Doctoral thesis, University of Eastern Finland Kohonen, K-M., 2022: Carbonyl sulfide fluxes and relation to photosynthesis in the boreal region. Doctoral Thesis, University of Helsinki Ryhti, K., 2022: Belowground carbon dynamics in Scots pine stands. Doctoral Thesis, University of Helsinki
France	M2 Mathilde Tinchant, PhD Lucas Medeiros, postdoc Margaux Brandon (ICOS OCEAN data)
France	Ecosystem data: master Clues U. Paris-Saclay courses
France	Ecosystem : PhD

France	"Fête de la Science 2022: Atelier CO2" (7-17 oct. 2022) animated by M.Delmotte (6 groups of 8-10 students at ENS; 20 groups of 6-12 students at OVSQ)
France	12 students (Middle school, 9th grade – 3ème) hosted at LSCE/ICOS for one week, and 5 classes visiting LSCE/ICOS
France	Field campaign "Atmosphère et Climat" organized by I.Pison (25-29 april 2022) for 14 Master students (M1 – PEPS, Univ. Paris Saclay) at Trainou ICOS station
France	Carbon cycle course at Centrale Supelec (40 students) given by M.Delmotte
France	PhD: Approche atmosphérique multi-composés pour la caractérisation des sources d'émission de CO2 et de polluants à Paris, Laura Bouillon
France	PhD: Evaluation des émissions de de CO2 et CH4 en Ile de France à partir des mesures de colonnes totals, Josselin Doc
France	Internship: Profils verticaux du CO2 au-dessus de Paris, O.Culeux, M2 PEPS, UVSQ
France	Internship: Modélisation des profils verticaux de CO2 et NOx au-dessus de Paris, J.Doc, M2 SDUEE, Sorbonne Univ.
France	Internship: Analyse des concentrations en gaz à effet de serre mesurées à bord du Marion Dufresne dans le cadre du projet MAP-IO, A.Coulon, M1, UVSQ
France	Internship: Caractérisation des émissions européennes de CH4 et CO2 lors du transect GHASS2, J.Louvet, M1, IMT Lille-Douai
France	Internship: Quantification des émissions chypriotes de CH4 à partir de mesures aéroportées, A.Palagi, M1, IMT Lille-Douai
France	Report: Les Carnets du GREC francilien: émissions de gaz à effet de serre en Ile de France: bilan et evolution (I.Albarus et al., 2022)
Germany	B.Sc. thesis at University of Freiburg: „Vergleich der Energiebilanz eines trockengeschädigten Kiefernwaldes mit einer Neuanpflanzung am selben Standort im Sommer 2021", https://freidok.uni-freiburg.de/data/227142
Germany	B.Sc. thesis at University of Freiburg: „Vergleich der sommerlichen Kohlenstoffbilanz eines dürregeschädigten Kiefernwaldes mit einer Neuaufforstung am selben Standort", https://freidok.uni-freiburg.de/data/227141
Germany	Lecture by A. Christen at Université de Strasbourg, 13.12.2022: „Klimawandel und terrestrische Ökosysteme im Wandel"
Germany	Lecture by A. Christen at Public Climate School Freiburg, 10.11.2022: „Das Schicksal des Kohlendioxids im Klimasystem"
Germany	Public lecture by A. Christen at Forum Merzhausen, 09.11.2022: „Klimawandel in unserer Region"
Germany	Site visit and sampling at CVOO with West African students during WASCAL floating university on RV Maria S. Merian (MSM106); time series data used for teaching purposes
Germany	Global Atmosphere Watch Training & Education Centre (GAWTec) Course #38 on greenhouse gases (March, 2022 @ DWD Meteorological Observatory Hohenpeißenberg/ICOS Station HPB)
Germany	6th WCC-SF6 Training and Education Course, organized by National Institute of Meteorological Sciences, Korea, Online Course

Germany	Usage and discussion of data in the following lectures and seminars of Bioclimatology Group, University of Göttingen: 'Bioclimatology', 'Ecosystem-Atmosphere Processes', 'Experimental Bioclimatology', 'Global Change', 'Klima- und Bodenschutz', 'Chemistry/Physics', 'Physik für Forstwissenschaftler'
Germany	MSc. Thesis in Forest and Ecosystem Science - Cheyenne Rueda Lagasse (09.2022): " Water use efficiency variations and its adaptation across different Northern and Southern European regions", Bioclimatology, University of Göttingen, supervisors: Christian Markwitz, Anne Klosterhalfen
Germany	BSc. Thesis in Ecosystem Sciences - Ezekiel E. Mjema (04.2022): „The exchange of CO_2, water and energy between forest ecosystems and the atmosphere. A comparison of eddy covariance systems in Hainich National Park, Germany", Bioclimatology, University of Göttingen, supervisors: Anne Klosterhalfen, Franziska Koebsch
Germany	BSc. Thesis in Forstwissenschaften und Waldökologie - Julius Koch (04.2022): „Analyse der Wassernutzungseffizienz von zwei unterschiedlich bewirtschafteten Waldökosystemen", Bioclimatology, University of Göttingen, supervisors: Anne Klosterhalfen, Christian Markwitz
Germany	BSc. Thesis in Forstwissenschaften und Waldökologie - Leo O. Franke (10.2022): "Analysis of photosynthetically active radiation below and above canopy at Hainich National Park", Bioclimatology, University of Göttingen, supervisors: Anne Klosterhalfen, Franziska Koebsch
Germany	BSc. Thesis in Forstwissenschaften und Waldökologie - Nils Birk (10.2022): "Evaluierung von statistischen Modellen zur Schließung von Datenlücken in automatischen Bodenrespirationsmessungen", Bioclimatology, University of Göttingen, supervisors: Anne Klosterhalfen, Christian Markwitz
Germany	Video in cooperation with ENLIGHT and Green Office of University of Göttingen, February 2022 - Franziska Koebsch: „Was macht der Klimawandel mit dem Wald? Ragna fragt nach(haltig)", https://www.youtube.com/watch?v=h0Sv6OvCZfo
Germany	Lecture for Saturday Morning Science, 30. April 2022 - Anne Klosterhalfen: „Dialog zwischen Wald und Klima", Bioclimatology, University of Göttingen
Germany	Outreach Event, 09. July 2022 - Fünfte Nacht des Wissens, Univeristy of Göttingen
Germany	Multiple Excursions to Hainich flux tower site with student groups of University of Göttingen and Forestry Research and Competence Centre Gotha
NLD	MSc thesis "27-years of GPP flux measurements at Loobos" by Jessie Beirnaert
NLD	MSc thesis "Quantifying Changes in Moisture Sources and Carbon Uptake During the 2018 Summer Drought in Scandinavia " by Malva Laurelin
NLD	MSc thesis "Eco-evolutionary optimality for coupled photosynthesis-stomatal conductance modelling" by Sebastiaan Heins
Norway	CAGE-Center for Arctic gas Hydrates, University of Tromsø, pre-cruise workshop lecture on greenhouse gas observations
Norway	How we use observations and machine learning to find the ocean carbon uptake – RapidVERIFY, YouTube lecture
Spain	The El Arenosillo ICOS data are used in a Thesis (in development since February 2021) to investigate the carbon monoxide (CO) and methane (CH_4) at El Arenosillo region.

Spain	Master in Oceanography ULPGC: CO_2 and Ocean Acidification February 2022
Spain	Thesis in progress: Observation and analysis of the carbonate system and air-sea CO_2 fluxes in the Northeast Atlantic and Western Mediterranean
Spain	Scientific visits for students have been organized at Izaña atmospheric station.
Spain	Omaira García (Izaña) gave a scientific talk within the programme Aula Morán of the Spanish Meteorological Association. April 2022
Sweden	ICOS Sweden stations are often visited during 1-day excursions as part of courses at different levels or are the base for field courses. e.g. Greenhouse gases and biochemical cycles (LU, MSc, stations involved: SE-Htm, SE-Sto); Krycklan Watershed course (SLU, phd, stations involved: SE-Svb, SE-Deg)
Sweden	Data from ICOS stations are often used for calculation exercises or examples within different courses at university or in material developed for schools. E.g. Meteorology course for earth scientists (UU, BSc, station: SE-MFT Östergarnsholm)
Sweden	Thesis examples: Hugosson, K. 2022. Evaluation of the variation in albedo over snow-covered forest in Northern Sweden and Finland. Gothenburg Univ. https://hdl.handle.net/2077/71717 Tuomaala, E. 2022. Net ecosystem exchange in habitats of a permafrost peatland and a review of the impacts of climate change on its carbon fluxes. Helsinki University. (http://urn.fi/URN:NBN:fi:hulib-202209303591)
Switzerland	Practical Course "Measurement methods for fine dust and trace gases" (Praktikum: Messmethoden für Spurengase und Feinstaub), University of Basel
Switzerland	Lecture "Urban Climatology", Autumn Semester, University of Basel
Switzerland	Course on "Stable Isotopes", Autumn semester University of Bern
Switzerland, Germany	Global Atmosphere Watch Training and Education Centre (GAWTEC), course # 38, 07 – 18 March 2022
Switzerland, Germany	Global Atmosphere Watch Training and Education Centre (GAWTEC), course # 39, 19 – 30 September 2022
Switzerland	The 6th WCC-SF6 Training and Education Course, 01 – 03 November 2022
Switzerland	Visit of the OCCR Summer School at Jungfraujoch, 12 August 2022
Switzerland	Visit of BKW Summer School at Jungfraujoch, 13 August 2022
Switzerland	Master Thesis Pascal Bregenzer "Implementation of Surface Urban Energy and Water Balance Scheme (SUEWS) and Solar and Longwave Environmental Irradiance Geometry model (SOLWEIG) for two investigation areas in Basel", University of Basel
Switzerland	ICOS presented at ETH Zurich's public science program Treffpunkt Science City, 27 November 2022, Zurich

List of Main ICOS National Network Meetings

Country	Meeting / study day / ...	Time	Place
Belgium	ICOS Belgium annual meeting in Louvain-la-Neuve. Including station visit at Lonzée	9 June 2022	UCLouvain

Czechia	Meeting of the ICOS CZ community within international conference: QUO VADITIS Agriculture, Forestry and Society under Global Change? From understanding past and present Earth's processes to adaptations for the future.	19th–21st September 2022	Velké Karlovice (Czech Republic)
Denmark	Spring meeting DK ICOS	March	Zoom
Denmark	Several meetings involving Cop. Uni and DTU with ministries of education and research + min of Climate	Summer/Autumn	Zoom/Physical
Finland	ICOS Finland new FIRI funding kick off meeting	22.4.2022	Zoom
Finland	ICOS Finland board – spring meeting	31.5.2022	Zoom
Finland	ICOS Finland board – autumn meeting	10.11.2022	Zoom
Finland	ICOS coffee	every Thursday	zoom/FMI
Finland	ICOS Finland annual meeting + party	9.12.2022	FMI premises
France	Ecosystem virtual meeting	May 2022	Virtual
France	Obs4clim : link with ACTRIS and IAGOS at national level	Dec 2022	Lille
France	Journées ICOS-France 2022	8-9 Nov. 2022	OVSQ, Guyancourt
France	OBS4CLIM KickOff meeting	13. Jan. 2022	Toulouse
France	OBS4CLIM Annual meeting	12-13 Dec. 2022	Lille
Germany	Annual ICOS Germany National Network Meeting	30.11. – 01.12.	UFS, Zugspitze
Hungary	ICOS Hungary consortium kick-off meeting	6 October 2022	Sopron
Italy	JRU Meeting	26/05/2022	online
NLD	ICOS National Assembly	Aug-2022	Utrecht
NLD	National Earth Science Congress	Mar-2022	The Hague
Norway	ICOS Norway Annual Meeting 2022	07-08/11/2022	Oslo
Norway	ICOS Norway General Assembly	24/11/2022	Online
Spain	Meetings with other Spanish research groups were held in order to recruit new stations for ICOS Spain network. The outcome of these meetings opens the possibility of incorporating a new atmospheric station in the next years.		On-line
Sweden	ICOS Sweden internal meetings	5 x	online
Sweden	ICOS Sweden Management meetings	2022-07-01; 2022-12-16;	online

Sweden	ICOS Sweden Management meeting	2022-08-26	Arlanda
Sweden	ICOS Sweden Steering Committee Meetings	2022-01-12; 2022-02-28; 2022-10-27	Online, October: Uppsala/Norunda
Switzerland	ICOS Davos Spring Meeting	2 May 2022	Zurich
Switzerland	HFSJG (Jungfraujoch) user meeting	20 May 2022	Bern
Switzerland	ICOS Switzerland Labelling Party	7 July 2022	Zurich
Switzerland	ICOS Switzerland Annual Meeting 2022	31 August 2022	Basel
Switzerland	HFSJG (Jungfraujoch) Board meeting	21/22 October 2022	Interlaken

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

Country	Event	Time	Place
Belgium (DRC)	PRECOP27 in Yangambi with many African participants	3 – 5 October	Yangambi
Belgium (DRC)	Scientific visit by KIT scientists	May	Yangambi
Belgium (DRC)	Frequent visits by media and international organisations (data availble via a vistors book)	Year long	Yangambi
Belgium	Site visit by a group of farmers	9 June	Lonzée
Belgium	Site visit for the TERRA innovation day	31 May	Lonzée
Belgium	National science day: visit on board of the RV Simon Stevin	27 November	Antwerp
Belgium	Klimaatlink: presentation of educational kits on the topic of Climate Change for high school teachers	25 October	Antwerp
DK, FI, NO, SE	Co-organisers of ICOS Nordic meeting		Zoom/virtual
Germany	ICOScapes Exhibition with German ITMS poster	August 2022	Fed. Ministry for Digital and Transport (BMDV), Berlin
Italy	Webinar "After COP26"	23/09/2021	online
Italy	First ICOS Italy Conference	27-28/09/2022	Rome
Italy	Workshop dedicated to 25 years of activity for Lampedusa Observatory	6/12/2022	Rome
NLD	Local host of ICOS Science Conference 2022	Sep-2022	Utrecht
NLD	Transcom	Sep-2022	Wageningen
NLD	GGMT	Sep-2022	Wageningen
NLD	Ruisdael Urban Campaign	Sep-2022	Rotterdam
NLD	Loobos field campaign	May-2022	Loobos

List of Main Events Attended by ICOS National network staff

Member	Workshops and conferences attended	Time	Place
All	ICOS Science conference 2022	13-15 Sep	Utrecht
Many	TRANSCOM-2022 (Atmospheric Tracer Transport Model Intercomparison Project Meeting)	Sep-2022	Wageningen
Many	21th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Measurement Techniques (GGMT-2022)	Sep-2022	Wageningen
Many	EGU General Assembly 2022	23-27 May	Vienna/ online
Many	AGU Fall meeting,	December	Chicago
BE, IT	ICOS Italy conference	27-28 Sep	Rome, Italy
BE	OSPAR ICG-OA Meetings		Online
UK, DE	ICOS OTC data workshop	Dec 2022	
NLD	Ruisdael Urban Campaign	Sep-2022	Rotterdam
FI	Suopäivä, The Peatlands Day. Suoseura ry, Finnish Peatland Society, 20 May 2022.	May 2022	
FI	Biogeomon, Tartu (Estonia), 26-30 June	June 2022	Estonia
FI	ACCC & Finnish Atmospheric Science Network Conference 2022, Tampere (Finland), 21-22 November 2022.	November 2022	Tampere, Finland
Finland	OECD-CRP Sponsored Conference - Peatlands for climate change mitigation in agriculture	October 4-5,	,Aarhus, Denmark
Finland	COP27, Sharm El-Sheikh, Egypt, 6-20 November 2022		
France	Open Science Conference on Eastern Boundary Upwelling Systems (EBUS): Past, Present and Future	13-23 Sep 2022	Peru/online
Germany	Workshop on the potential of establishing eddy-covariance measurements at viniculture sites	07.03.2022	Geisenheim University
Germany	Workshop on standardization of chamber measurements hosted by German Soil Science Society (DBG)	18.05.2022	Online
Germany	Integrated Greenhouse Gas Management System (ITMS Germany), Kick-off meeting	18.-20.10.2022	Jena
Germany	Ocean Science meeting	28.02.– 04.03	Online

Germany	SOLAS summer school	13. – 17.06.	Online
Italy	Webinar "After COP26"	23/11/2021	online
Italy	International Workshop C4 "Climate Change and Carbon Cycle"	22-24/06/2022	Pisa
Italy	First ICOS Italy Conference	27-28/11/2022	Rome
Norway	ReGAME annual meeting	13-14/12/2022	Oslo
Spain	Omaira García (Izaña) attended to IX Remedia Workshop.	21-22 April	Córdoba
Spain	Pedro Pablo (Izaña) participated in European Obspack 2022 (ObspackEU-2022). A new collection of CO2 and CH4 measurements from all European asxasxs stations.	May-Jun 2022	On-Line
Spain	QUIMA research gruop (CanoA-Vos) has participated in the VII International Symposium on Marine Sciences 2022	6-8 July 2022	Las Palmas de Gran Canaria
Spain	QUIMA research gruop (CanoA-Vos) has participated in the XXI Iberian Seminar of Marine Chemistry (SIQUIMAR)	6-8 July 2022	Las Palmas de Gran Canaria
Spain	David González Santana attended to 5th International Symposium on the Ocean in a High CO2 World	12-16 September 2022	Lima
Sweden	Swedish Climate Symposium 2022	16-18 May 2022	Norrköping
Sweden	4th Baltic Earth Conference	30 May – 3 June 2022	Jastarnia

Annex 2

Availability of ICOS data

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

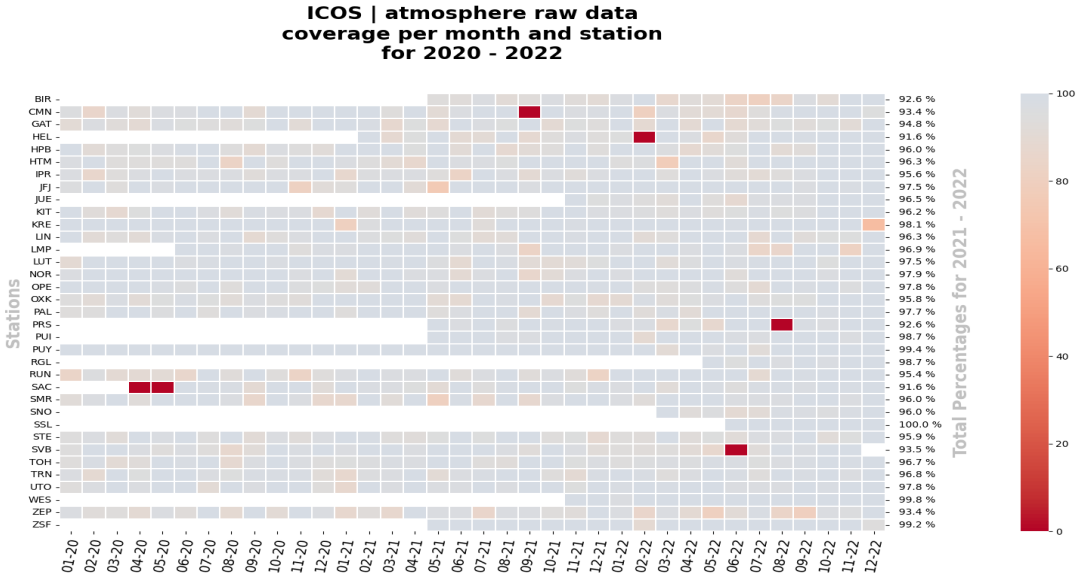


Figure 2 ICOS atmosphere raw data coverage per station 2017-2022

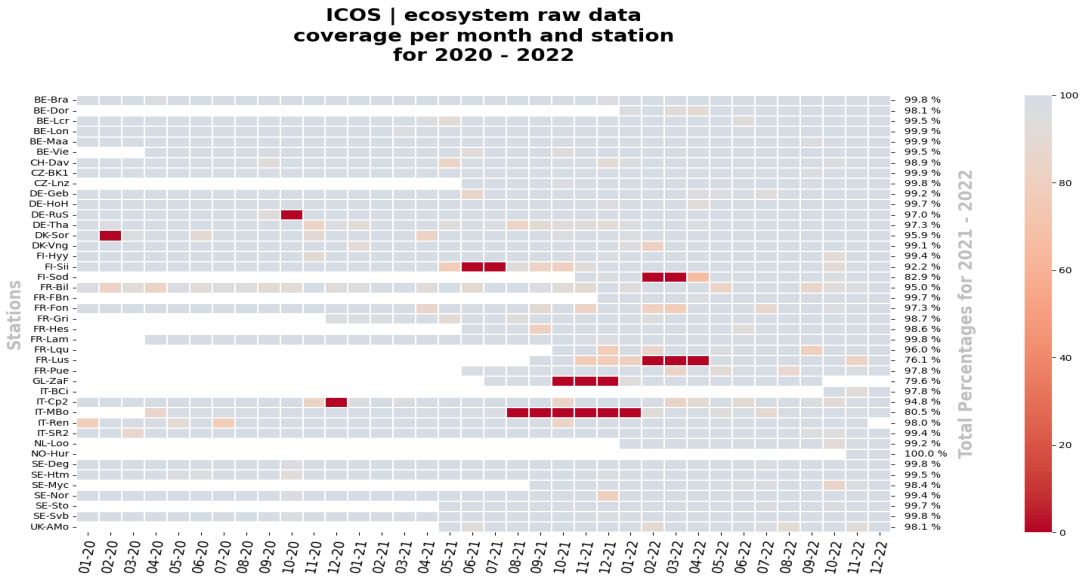


Figure 1 ICOS ecosystem raw data coverage per station 2017-2022

Annex 3

Report of co-operation of ICOS and ACTRIS Head Offices

(As requested by the Academy of Finland / Finnish Research Infrastructure Committee)

Introduction

The research infrastructure committee has included a requirement on the synergies between the ACTRIS ERIC and ICOS ERIC Head Offices in their decisions in recent years, including the latest funding decisions for both Head Offices.

To facilitate the planning, the Academy of Finland held a meeting on 25th of August 2022 together with ACTRIS and ICOS representatives to discuss possibilities of synergies between the two Head Offices. The FIRI request was detailed to comprise a jointly produced, few pages long report, delivered by the end of November 2022.

Based on a further request received 15 December, we have now added more concrete examples of co-operation, quantifying the efforts where feasible, and included a paragraph of "considerations" to every item.

The activities of each ERIC is defined by its respective Statutes, confirmed by the European Commission and member countries. The statutes of ICOS and provisional statutes of ACTRIS are provided as annexes 1 and 2 to this report.

It is important to note that the European research infrastructures cooperate, exchange experiences and commonly develop best practices as part of their regular operations. This is especially true for research infrastructures hosted in the same country, and there has been cooperation and knowledge sharing between the ICOS ERIC HO, ACTRIS and EURO Bioimaging Head Offices from the beginning.

Thus, a lot of added know-how is gained in Finland through the establishment process of ICOS, Euro BioImagining and ACTRIS Head Offices. By sharing experiences and best practices also in future strengthens the HOs, and the position of Finland in the European RI landscape.

Financial framework

The financial framework of the two offices is determined by the statutes and the decisions of the General Assemblies. The annual funding for the core activities is for ICOS ERIC 1.5 million € including so-called common contributions from all member and observer countries, and host contributions from Finland and France. For future ACTRIS ERIC the core funding is 1.0 million € for the first financial period, ending in 2025, including membership contributions and host contributions from Finland. Large part of the core funding goes for the Director General, who is the legal representative of the ERICs and the leader of the whole Research Infrastructure and is not negotiable. The number of personnel working on the core funding is 8 for ICOS ERIC (as planned in the last application of funding to the Finnish Academy, but less funding was received), and 6-7 persons planned for ACTRIS ERIC. The foreseen budget for salaries and legal social security costs forms for both ICOS ERIC and ACTRIS approximately 60-70% of the whole annual budget, with these constrained personnel resources. Thus, it is evident that the two Head Offices need to aim for wise use of resources in their day-to-day management.

ICOS has developed a system of distributed Central Facilities, each of them mainly supported directly by their hosting countries. Beside the Head Office supported by Finland these are e.g. the data centre ("Carbon Portal") supported by Sweden, the Thematic Centres supported by France, Italy, Norway, the UK, Belgium and Finland, and the Central Laboratories supported by Germany. For each of these facilities the host country contributes the major part of the costs. It is a matter of trust among the ICOS

countries that these host contributions are sustainable. According to Financial Rules of ICOS ERIC, the host contribution should not exceed 80% of the total costs. A change of this 80%-20% rule is currently discussed for the next funding period (2025-2029). In ACTRIS the sharing of the costs for the first five-year period is agreed to be 70% by the host country and 30% through membership contributions. In Finland the Host contribution of both Head Offices are shared equally between FMI and Academy of Finland.

External project funding is and will be a crucial way to gain more resources, for the development of the RI and to allow performing tasks that would be difficult to complete otherwise. ICOS ERIC has been successful in gaining external funding and this is visible in their international visibility and strong position in the European landscape. Overheads of EU-funded projects are also contributing to general management of the HO. ACTRIS ERIC is foreseen to be established in the coming months and after that ACTRIS ERIC can be directly a beneficiary or a coordinating partner in EU projects targeted to research infrastructures. Currently ACTRIS is participating in several projects through the hosting institutes in different countries.

Realised and planned synergy-increasing activities

A working group between the ICOS ERIC Head Office and ACTRIS Head Office preparation team was established in 2021. The group compiled a list of synergy topics such as the possibility to use common service providers (e.g. for occupational health, ICT support, 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). In 2022, the work continued e.g. with the following aspects:

Synergies on premises

Realised & Planned: Co-locating Head Offices, negotiations with FMI

In 2022, the two HOs have agreed on locating the premises close to each other if this was possible from the FMI side. The meeting rooms and multi-work spaces could be shared and used jointly. The negotiations with the FMI are still ongoing and more concrete plans can be developed jointly once the FMI has concluded their new internal strategy on the arrangements of the works spaces, due at the end of 2022. In case the negotiations will not be successful for some reason, the two ERICs may look for alternative solutions jointly. In the long run, sharing facilities is expected to result in efficient use of the premises and savings in rental costs, or at least not increasing costs for both organisations.

New information: In autumn 2022 both organisations have discussions in their planning days about hybrid working modes and needs of the staff. This will be the basis for space planning jointly together by the two organisations. ACTRIS is currently located within the FMI premises, working within the government rules for the office space. The plan is to continue the working mode in the open space office, with proper facilities for meetings and quiet working. As the staff will continue working remotely to some extent, the office space is planned so that there would be no dedicated seats, thus empty spaces, but at the same time taking into account the needs for likely expansion during the next 5 years.

For ICOS, the plans are still very preliminary and tied to the timeline of changes. In 2023, ICOS ERIC is coordinator of 3 and beneficiary in 9 EU-funded projects (3 of which are starting and 4 of which are ending; number of projects is now exceptionally high as several projects were extended due to COVID-19.) The projects have a significant impact of Head Office finance, but they also affect the need for space for project-related staff and remote meeting facilities.

Consideration: As the discussions with FMI / Senaattikiinteistöt are still ongoing, it is not possible to provide exact numbers, but the order of magnitude can be estimated. ICOS is currently paying for 104 m^2 of meeting rooms, corridors and lobby / multifunctional area, which are used sporadically. If ACTRIS HO was not collocated with ICOS, it would need roughly the same area of such spaces. By collocating the Head Offices the same spaces can be used, resulting in a 104 m2 area saving compared to the non-collocated HOs scenario. Assuming the current rent level ICOS is paying this means an annual saving of 25 000 - 30 000 € for the two ERICs combined.

Synergies on procuring third-party services

Realised: The two HOs have shared experiences in building the ICT solutions necessary for day-to-day operations. ICT systems can be combined only in some specific cases, as the two RIs have different approaches. ICOS ICT is run locally, in-house, at the Carbon Portal at Lund, Sweden, whereas ACTRIS is hosting all its ICT services in Helsinki and is looking for a fully cloud-based system. However, for example in the first negotiations on the ICT services for ACTRIS ERIC, the ICOS HO was participating to see whether joint activities or procurements would be possible. The economic benefit here is, however, limited.

Planned: Cooperation in procuring third-party services

Selecting the right outsourced web-based services from third parties related to, for example, ICT, HR or Communications (teleconferencing, discussion boards, conference-organising) is consuming resources and requires that the users understand the activities. The synergies can be found in the benchmarking phase, even if the two ERICs end up making different decisions in the end. Sharing and learning from experiences saves time and money.

New information: In autumn 2022 both organisations have been discussing with the IT provider that ICOS uses and ACTRIS is considering, on possible synergies that could be gained through joint services. As explained above, these possibilities are somewhat limited due to the different structure in organising the services. ICOS ERIC Head Office gains substantial benefits in having the Carbon Portal that can provide some services for the Head Office. ACTRIS has different task sharing between the ACTRIS Data Centre and the Head Office, and the ICT services necessary to run the operations are organised fully locally in Helsinki. Before the Christmas break, the company gave us the information on potential synergies (Annex x). If the two HOs are working in collocated premises, it is technically possible to provide a shared firewall, shared printing system and shared wireless network. The amount of potential saving depends on the level of data security needed between the organisations and the type of juridical contract between ICOS ERIC and ACTRIS ERIC. For software licences etc. no cost savings are foreseen as the contracts need to be organisation specific and licenses are per user. The estimated potential savings are some thousands of Euros annually. It is important to note that this work is still ongoing, as the company is currently analysing the needs of ACTRIS ERIC Head Office. The company can provide more detailed information on the monetary benefits only after this work and the question on the location of the premises is concluded.

Consideration: There has also been discussion on the economic benefit from common tendering and common outsourcing of other services, but it is limited. As ACTRIS ERIC and ICOS ERIC will be two different legal entities and they need to be treated separately by the service providers. The same limitation applies to other contracted services. (as stated in e.g. in the annexed letter from the IT service provider). The goal of the two ERICs is to seek synergies and financial benefits wherever it is possible, through bilateral agreements.

Cooperation and shared personnel resources

Realised: Communications cooperation

ACTRIS and ICOS communication teams have cooperated actively in earlier years, both between the Head Offices and through ENVRI activities. One such activity was the jointly organised hackathon to market the data. In 2022, due to personnel changes in ICOS and the added workload due to the ICOS Science Conference, the cooperation was limited to the ENVRI and to the Kumpula networks. ACTRIS and ICOS HO communications staff are meeting regularly to share best practices, together with FMI and the other main actors in the Dynamicum building in Kumpula.

Realised: Organisation of Innovation in Atmospheric Measurement Techniques workshop

ICOS and ACTRIS Head Offices (and IAGOS) cooperated in connection with organising an one-day free-of-charge Innovation workshop held online 2nd June 2022. The audience consisted e.g of RPO's, RIs, industrial companies and air-quality networks. The event was advertised on both organisations', websites, newsletters and Twitter accounts.

https://www.actris.eu/news-events/events/workshop-innovation-amt-22

https://www.icos-cp.eu/event/1161

Planned: Communications cooperation

During 2023, the HO communication teams will continue to develop joint activities, also including other RIs, to engage common stakeholders such as policy makers and industry. This work extends beyond the RI core activities and supports common EU funded projects such as ATMO-ACCESS.

Planned: Co-recruitments

The two HOs have been discussing together on possibilities for co-recruiting for non-core activities of the RIs especially when the position for one RI would be only part time. For instance, the aforementioned ICT expertise or part of the HR or communication support could be a joint employment. Since the funding available from the projects varies from year to year, a common pool of experienced project officers may be an efficient way to keep experienced staff. Progress can be expected later, within 3-5 years, when both HOs are established fully.

New information: ICOS has opened a position for project manager. "… fixed-term until 31.12.2024, to be filled as soon as possible. There is a possibility for an extension depending on project funding." This "extension" may well take place fully or partially in ACTRIS, if project funding situation supports that.

Consideration: It is important to realise that even though the two organisations fully agree on resource wise use of funding and personnel, co-recruitment is not necessarily easy for several reasons. First, especially for project management, the personnel needs fluctuate strongly annually and inter-annually. During the first years of operation ACTRIS ERIC may have substantially less projects to be managed than ICOS ERIC. How then to divide the resources and costs so that it is fair for both organisations from year to year? Secondly, we have seen during the last year that the recruitment of administrative personnel is not necessarily easy, and proposing a contract and work time under two different supervisors and that would be part time for both organisations is not necessarily increasing attractivity of the positions. However, we are doing our best in searching for best opportunities for joint recruitment in positions that allow the sharing of the work time without problems in loyalty or responsibilities.

Even though the co-recruitment appears to be challenging, there is a lot of potential in cooperation between the existing / planned personnel of the ERICs. Sharing of expertise and best practices leads to more effective and efficient work and use of resources. In such small organisations this does lead to cost savings due to reduction of workforce, but will decrease the pressure for increasing the workforce. Once ACTRIS ERIC is established and the tasks are properly running the type of cooperation currently practised between the communication teams is planned to extend also to other units of the ERICs.

Collaboration in project planning and coordination in European RI landscape

Realised: Collaboration within ENVRI-field infra-projects

Currently ACTRIS and ICOS are working together in ENVRI-field infra-RI projects such as ENVRI-FAIR, ATMO-ACCESS and KADI. Planning of participation of both RIs with several other environmental RIs for a new INFRA-SERV project is ongoing at the RI level.

Planned: Collaboration within EU-projects

For 2023, RI-URBANS (coordinated by an ACTRIS partner) and ICOS Cities (coordinated by ICOS ERIC) projects have planned close cooperation that involves ACTRIS, ICOS and IAGOS. The most important synergies are the development of a common framework to integrate urban observations and services to cities into the portfolio of European Environmental Research Infrastructures, common data approaches and joint communication efforts.

New information: As a practical example of cooperation between the projects coordinated by ACTRIS and ICOS, ICOS Cities is running a now well-established webinar series on topics that are relevant to the project. In 2023 this series co-operates with RI-URBANS, and CoCO2 projects.

ERIC Forum is an annual networking event initiated by the Commission, and also a joint Horizon-funded project between European ERICs. Not being an ERIC yet, ACTRIS is so far participating as an associated partner. ICOS has been leading the communications WP in the previous project culminating in ERIC Toolkit providing support for most practical questions relevant to ERICs, including financing, administration, human resources, communication, impact and evaluation. https://www.eric-forum.eu/toolkit/

Considerations: As per their statutes ICOS ERIC and future ACTRIS ERIC implement the strategic decisions of their General Assemblies. The General Assemblies direct the way how the two organisations operate and cooperate within the European landscape including more than 20 research infrastructures. The cooperation among all the relevant RIs is essential and crucial for the success of both RIs.

Collaboration in training and event organisation

Planned: Training that is not specific to the field of an individual RI can be obtained together. In 2023, the Head Offices will check the need for training needs related to developing the necessary skills and competencies of their personnel. In cases where the needs meet, the HOs may procure common training. Examples of this could be hybrid meeting facilitation and project proposal writing.

Furthermore, sharing best practices e.g. in event organisation can reduce the workload, costs, and lead to added value. However, it needs to be kept in mind that the two RIs and their scientific fields are different.

New information: ICOS has organised a Science conference five times. The biannual ICOS Science conference is the main European event in the area of Greenhouse Gases, and the largest activity in ICOS facilitating science by providing researchers opportunities to present their work, learn and network. For the 2022 edition, 2000 working hours from permanent staff as well as work of 2 summer trainees were used to create an event of 400 participants. ACTRIS organised its first science conference in spring 2022 with more than 300 participants and is planning to organise the conference biannually. Lessons learned in all steps of preparing a fully hybrid major event are openly shared between the two ERICs. Organising large conferences is a huge and expensive work, and knowledge sharing increases the efficiency of the organisational work, and choosing the best technologies etc., bringing cost efficiencies in the resourcing of the personnel.

As requested by the Academy of Finland, this document is prepared in collaboration between ICOS and ACTRIS Head Offices. In addition to the above-mentioned actions, we anticipate that informal

cooperation between staff continues as usual, especially as now after COVID we are more present in the offices.

This report will be attached as an annex in the annual reports of the two ERICs as information to their General Assemblies.

Sincerely yours,

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