2022

ICOS Handbook

Knowledge through observations

ICOS

Integrated Carbon Observation System

ICOS Handbook 2022

Author:

Integrated Carbon Observation System (ICOS) Research Infrastructure

ICOS ERIC

Helsinki 2022

ICOS HANDBOOK 2022

Author: Integrated Carbon Observation System Research Infrastructure

Several dozens of people within the whole research infrastructure have participated in the writing work.

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ICOS HANDBOOK TABLE OF CONTENTS

Foreword

Greenhouse gases are transported in the atmosphere with the winds. They can travel even thousands of kilometres. Their mixing and distribution in the atmosphere impacts climate far away from the regions where the emissions originate. People who have not contributed to the burning of fossil fuels at all may be heavily affected by the climate crisis. The 2020s are seen as the decisive decade for climate action. In order to act in an informed manner, it is key to understand greenhouse gases; their sources, transport, sinks and finally their balance. Standardised in situ observations with broad geographical coverage are essential for this understanding.

The Integrated Carbon Observation System, ICOS, provides the necessary observational network throughout Europe, facilitating science and enabling better knowledge for decisions on climate change mitigation and adaptation.

ICOS has been born out of European scientific communities' grand idea of having a consistent, sustained measurement network operating under exactly the same technical and scientific standards. The first ideas were expressed already in the 1990s, but it took years and even decades to establish the ICOS research infrastructure as we know it today. Pursuing the common goal has driven the community forward, often with incredible engagement and tenacity when facing difficulties.

I suppose that it has been this unique combination of scientific excellence, technical competence and strong commitment to climate change mitigation that has convinced the European Strategic Forum on Research Infrastructure (ESFRI), the European Commission and many national ministries to support ICOS during the journey: from the first ESFRI roadmap in 2006 to an ERIC, to today's operational Landmark Infrastructure which has been identified by COPERNICUS as an integral part of the European CO_2 Monitoring and Verification Support Capacity. Building a greater ICOS community together with scientists, technicians and our stakeholders has been the base of our success. We are proud of and grateful for this achievement.

And we have even more ambitions: ICOS has also developed strong cooperation beyond Europe, is an officially accredited Observer of the UNFCCC, a regional network of the WMO Global Atmosphere Watch Programme and a Participating Organisation in GEO. Through this cooperation, we aim at a global operational observing system that supports the Paris Agreement with data on greenhouse gases, scientific analyses on carbon-climate feedback and direct observations of anthropogenic emissions.

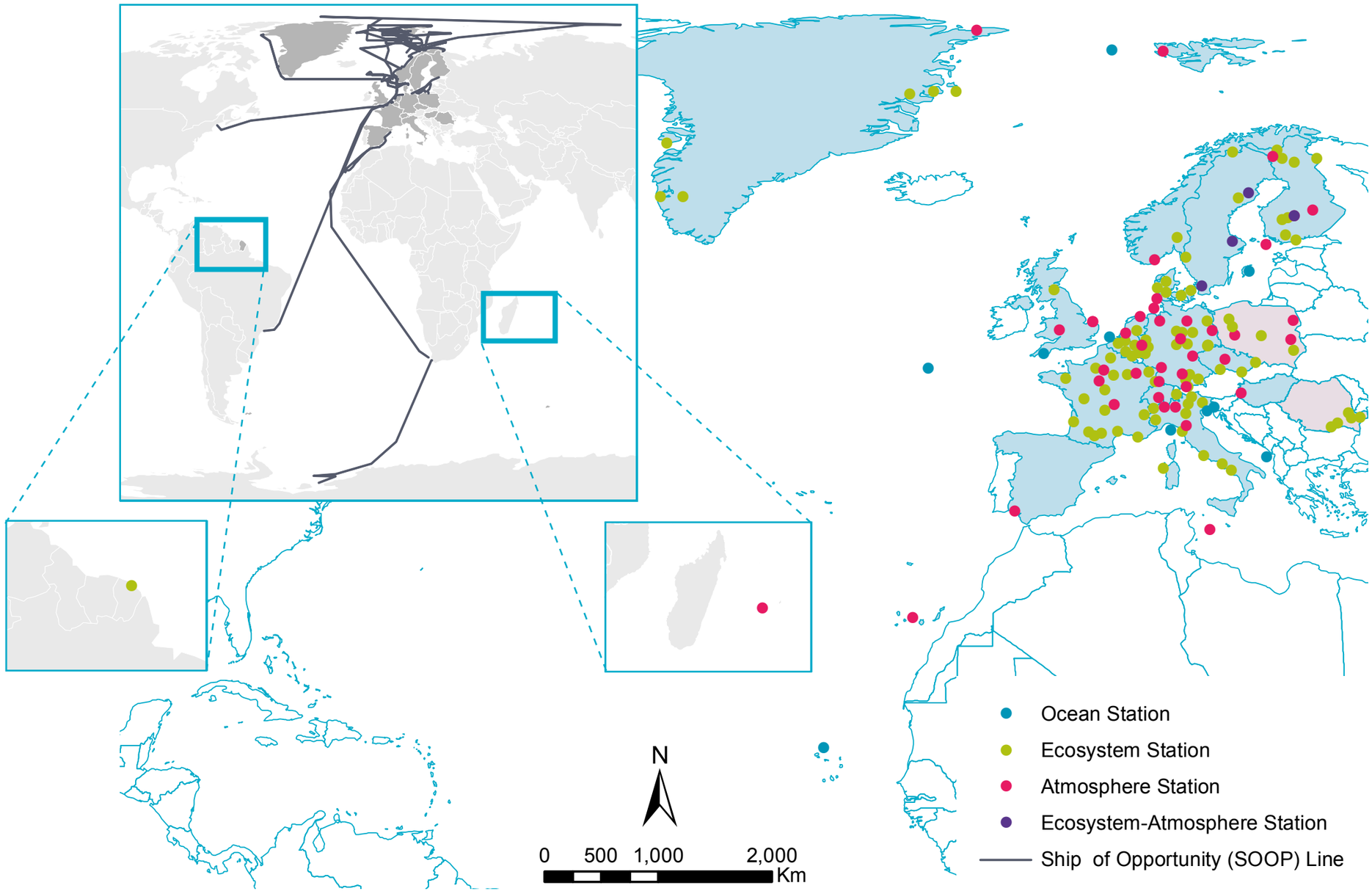
This book gives a comprehensive overview of ICOS research infrastructure, e.g. of its data processing and data life cycle, organisational structure and technical details about station requirements. It also describes the National Networks and the process for a country to join in ICOS. Novel in this edition, we have added those prospective member countries, Poland and Romania, which have announced their intention to join ICOS ERIC in the near future.

This is the third edition of the ICOS Handbook, published in 2022. In this regard, I want to thank the ICOS National Networks for their support in compiling the handbook, as well as the personnel in the Thematic Centres, Carbon Portal and in the Head Office for their efforts in producing this book. As is the matter with the ICOS research infrastructure in general, also here the whole is greater than the sum of its parts.

WERNER KUTSCH
Director General, ICOS ERIC

ICOS Station Network

In the map, light blue indicates current ICOS countries and light pink indicates prospective countries joining ICOS in 2023.



ICOS – Standardised greenhouse gas observations throughout Europe

The level of greenhouse gases in the atmosphere rises constantly, heating up our planet. Observing the levels of greenhouse gas emissions is essential to predict climate change and mitigate its consequences. ICOS produces standardised and high-precision greenhouse gas data from its Atmosphere, Ecosystem and Ocean stations.

Benefits of being a part of ICOS

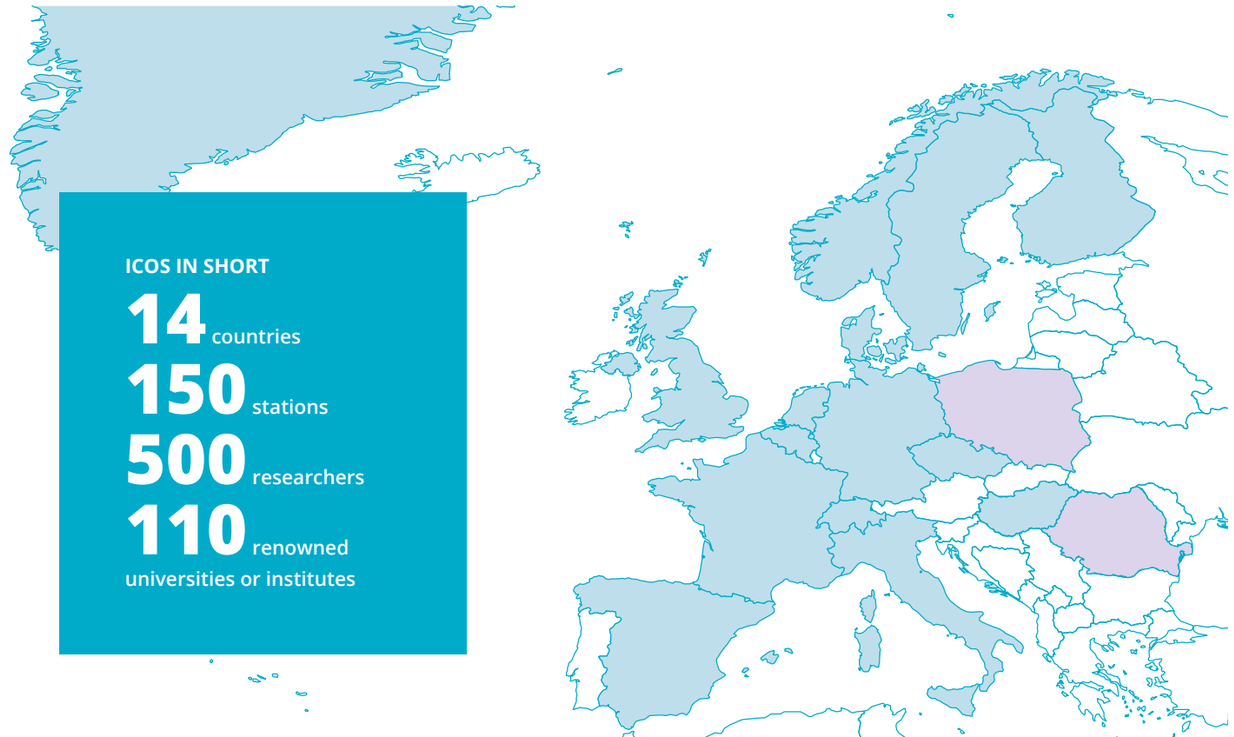
1 ICOS represents a community of scientists distributed over Europe.

2 We strengthen the scientific community by organising trainings and events.

3 We are well connected to European and global networks.

4 We promote the standardisation and curation of data.

5 We support our members who apply for funding in multidisciplinary consortium projects.



ICOS IN SHORT

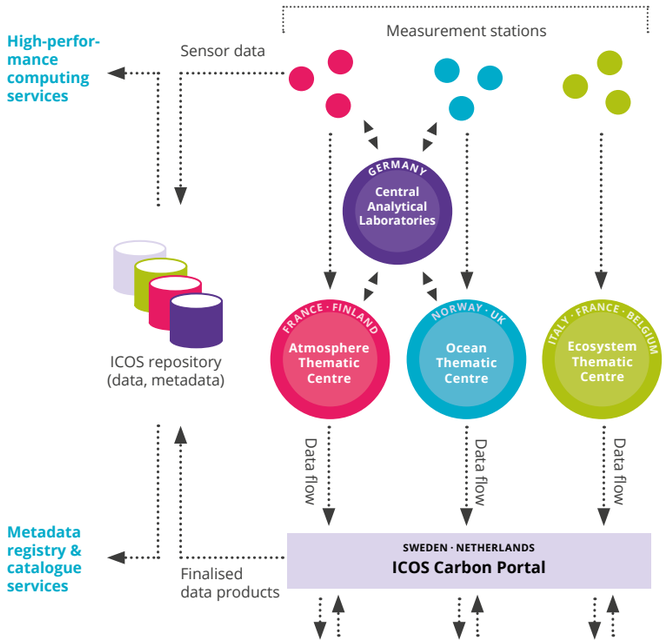
14 countries

150 stations

500 researchers

110 renowned universities or institutes

We produce high-quality greenhouse gas data open for all



Station labelling process ensures common ICOS standards and the data quality

The applicant sends a formal application via www.icos-ri.eu

Step 01 — ICOS evaluates the station location and technical requirements.

ICOS Head Office creates links between the station personnel and the respective Thematic Centre, which helps the station in the work.

Step 02 — Constructing and upgrading the station, evaluation and testing.

The station needs to meet ICOS standards, the Thematic Centre personnel can advise.

Step 03 — The ICOS General Assembly awards the ICOS label to the station.

The duration of the labelling process varies depending on the station characteristics.

1 AN OVERVIEW: Purpose, benefits and administration

Climate change brings immense changes to the Earth and to our life. To predict and mitigate this change, it is crucial to have long-term and standardised measurements of greenhouse gas emissions and sinks as well as their evolution. ICOS, which is short for the Integrated Carbon Observation System, is a distributed European research infrastructure (RI) producing these high-precision data on greenhouse gases. It provides standardised and open data close to 150 measurement stations across 14 European countries. The stations observe greenhouse gas concentrations in the atmosphere as well as carbon fluxes between the atmosphere, land surface and oceans. Thus, ICOS is rooted in three domains: Atmosphere, Ecosystem and Ocean.

ICOS data helps us to give an account of the Earth system and its response to climate change and other environmental challenges. The data generate scientific knowledge, which advances the fulfilment of the United Nations' Sustainable Development Goals and the European Union's Societal Challenges, especially those concerning climate change. ICOS supports efforts to comply with the Paris Agreement resolutions. It actively communicates to society that science-based knowledge is relevant to climate action and decision-making.

ICOS thus supports policy- and decision-making to combat climate change and its impacts. It is also important for ICOS to promote technological developments and demonstrations related to greenhouse gases by linking together research, education and innovation. One of ICOS' key features is the possibility of dynamically implementing technological and state-of-the-art scientific upgrades by introducing new techniques, instruments and observed variables.

The ICOS community consists of more than 500 scientists in both its Member and Observer countries and beyond. More than 110 renowned universities or institutes are a part of the ICOS community. The ICOS community has strong connections to colleagues and operators outside ICOS.

ICOS is a part of a diverse RI landscape. In Europe, ICOS collaborates with other European Environmental Research Infrastructures (ENVRI) to develop a clearer picture of the landscape, the core competences of each RI and possible cross-RI services. Moreover, ICOS participates in many external projects which in turn help us to be a cutting-edge research infrastructure. All ongoing projects are listed in Appendices of this handbook.

Internationally, ICOS participates in global initiatives such as the development of the Integrated Global Greenhouse Gas Information System (IG3IS) of the World Meteorological Organization (WMO). Furthermore, ICOS has since 2019 been an Observer organisation to the United Nations Framework Convention on Climate Change (UNFCCC). Thus, ICOS contributes to the work of the Convention and its Subsidiary Body on Scientific and Technical Advice (SBSTA) and can organise its own side-events in connection with the annual global climate negotiations (COP meetings). As an Observer also to the Intergovernmental Panel on Climate Change (IPCC), ICOS can actively foster the participation of the ICOS community in the writing process of IPCC's various reports.

ICOS has also formed deep connections to global data-integration efforts. ICOS' ecosystem flux data, for example, are well connected to FLUXNET, a global network of micrometeorological tower sites. Ocean data in turn are connected to the Surface Ocean CO_2 Atlas (SOCAT) and Global Ocean Data Analysis Project (GLODAP). Atmospheric data are connected to the WMO's Global Atmosphere Watch Programme.

ICOS' historical background

Although an ample amount of research and data on greenhouse gases had previously existed, scientists found that the data were often scattered and difficult to find and access. The quality and consistency of measurements were not guaranteed. Nor did the data turn into information that could easily be used by citizens and decision-makers. The scientific community concluded that the measurements of greenhouse gases needed to be harmonised and that the data that were gathered should be shared. That required deeper collaboration and interaction among the scientists and their home institutions.

In 2006, European scientists and their national support networks combined their efforts and initiated the ICOS RI, the Integrated Carbon Observation System Research Infrastructure. In the same year, the ICOS RI entered into the ESFRI (European Strategy Forum on Research Infrastructures) road map. The ESFRI road map identifies the new RIs of pan-European interest corresponding to the long-term needs of European research communities, covering all scientific areas, regardless of possible location. From 2008 to 2013, ICOS was designed and prepared in an EU-funded preparatory project. Since 2015, the ICOS RI has been coordinated and integrated by a legal body called the European Research Infrastructure Consortium (ERIC), established by a decision of the European Commission in November 2015. ICOS ERIC has its statutory seat in Finland. ICOS is one of 20 currently existing ERICs. ICOS ERIC has held a Landmark status in the ESFRI roadmap since March 2016.

Benefits of being a part of ICOS

ICOS fosters Europe's scientific competence and competitiveness by strategically pooling available resources linked to greenhouse gas measurements. By cooperating and creating a joint network, it is possible to further scientific excellence cost-efficiently. ICOS has been established to ensure the high-quality measurements of greenhouse gas concentrations and fluxes that are independent, transparent and reliable. In turn, this observational network will support governments in their efforts to mitigate climate change as well as hold them accountable for reaching their mitigation targets. ICOS Member and Observer countries receive support for their national inventories and capacity building. ICOS opens new opportunities for its Members and Observers to be connected with the European and global community of researchers.

The standardisation carried out in ICOS provides an example of the joint international efforts through which Europe has achieved global influence, and this plainly shows the strategic importance of ICOS. ICOS provides easy access to new methods and instrumentation. The high quality of reliable and comparable data is guaranteed by harmonised practices in the operations at its Thematic Centres and in the Carbon Portal data services used in data processing. These include, for example, Quality Assurance and Quality Control.

The main benefits of being a part of ICOS are summarised below.

Strengthening of scientific communities

ICOS is engaged in enhancing the readiness of scientific communities to tackle the current pressing climate-change-related challenges by organising science events that include, for example, a biennial ICOS Science Conference. In 2019, ICOS took the initiative of forming a drought task force to address the 2018 extreme drought event in Europe. This task force rapidly compiled relevant datasets and the analyses were discussed openly among the wider science community at the European Geosciences Union General Assembly 2019. The initiative resulted in a special issue with 14 papers in the Philosophical Transactions of the Royal Society B journal.

Advancing the standardisation and curation of data

ICOS has developed a broad range of standardisation protocols in order to ensure the highest observational standards for each ICOS station. One component of this standardisation for ICOS Atmosphere measurements is that the stations are centrally served with reference gases. The protocols are implemented during the ICOS station labelling process (described in detail in Chapter 2). This guarantees that all ICOS stations collect data that meet the agreed quality requirements. By going through the labelling procedure, the ICOS stations increase their reliability, participate in a near-real-time (NRT) data flow via the Carbon Portal and benefit from the curation and dissemination of the data.

Guidance, training and knowledge exchange

The ICOS Central Facilities (CFs) and Carbon Portal provide trainings, for example for stations' Principal Investigators, managers and technicians on any necessary issues. The aim is to stimulate the better use of ICOS-certified instruments and involve station staff in working groups for protocol development. Training also acts as a platform for exchanging ideas and knowledge on cutting-edge innovations and technologies related to the ICOS RI.

Funding opportunities

ICOS supports its partners to apply for multi-disciplinary consortium projects by providing timely information on the financial and administrative process as well as on the scientific and technical prerequisites and developments. For example, ICOS partners have participated in several successful EU Horizon 2020 projects, and the partnership with ICOS is explicitly mentioned in several Horizon Europe calls. All ongoing ICOS projects are listed in the Appendices.

Increasing international scientific networking

ICOS is well connected to European and global networks that are in charge of coordinating greenhouse gas observational activities or collecting and curating the data. Its voice is increasingly being acknowledged in international forums. ICOS has, for example, established a deep connection to domain-wise global data-integration efforts such as FLUXNET, SOCAT and GAW. During the past years, ICOS has become a respected and active participant in the advocacy work of climate change policy and management carried out in international organisations, such as the SBSTA of the UNFCCC. In 2019, ICOS became an observing Intergovernmental Organization to UNFCCC and has since then organised official side-events at the annual COP meetings.

Technology and innovation

ICOS' effectiveness in unifying the European climate science field has already had effects on technology and innovation. The wider the ICOS network is, the bigger its impact is on technology and innovation. ICOS is a single large procurer with high demands. Its industrial partners indicate that high ICOS standards drive them to develop new or improved measurement methods and hardware innovations and to increase their product quality. Suppliers of sensors and measurement instrumentation mention that having ICOS as their client counts as a quality certificate.

ICOS' mission

ICOS is a distributed RI conducting standardised, high-precision and long-term observations and facilitating research to understand the carbon cycle and to provide necessary information on greenhouse gases. ICOS-based knowledge supports policy- and decision-making to combat climate change and its impacts. ICOS is the European pillar of a global greenhouse gas observation system. It promotes technological developments and demonstrations related to greenhouse gases by linking research, education and innovation.

ICOS' vision for 2025 and beyond

Today and through the late 2020s, ICOS will produce highly standardised, robust in situ data and elaborated data products for science on the carbon cycle and for quantifying greenhouse gas emissions and sinks across Europe.

ICOS data are integrated into major global data systems and networks and meet the needs of international requirements, principles and agreements. ICOS Thematic Centres are established as centres of excellence in their domains and provide stable support for European and international networks.

The ICOS data are near-real-time and compliant with FAIR principles (meaning that the data are Findable, Accessible, Interoperable and Reusable). They are being utilised by a broad spectrum of users who employ them both for making scientific breakthroughs and for producing knowledge for climate action, as evidenced by ICOS' data-citation statistics. ICOS also has a vivid user community and an active dialog with it, which helps ICOS to improve its state-of-the-art data and to provide multiple services for science and society. Based on these services, ICOS is also able to quantify and separate fossil-fuel-related emissions, sources and sinks from natural greenhouse gas fluxes.

ICOS represents a strong European community of institutions investing in in situ observations, and it has established itself as an organisation from which relevant stakeholders seek advice. ICOS acts as a mediator between the greenhouse gas science community and the agencies that work on national inventories and the global stocktake. The biennial ICOS Science Conference is a hub for presenting the outcomes and impacts of observations. It also functions as a development, prioritisation and mediator forum. ICOS drives technical developments in order to improve analytical capacities, supporting industry partners to fulfil its high-quality needs.

Within the ensemble of ENVRI, ICOS is a strong European building block and supporter of a recently established global RI. This role, the benefits of ICOS to science and society, and an increased number of member countries have resulted in obtaining stable and sufficient resources to further sustain and develop the RI.

Organisational structure

The basis of ICOS' operations is the measurement network that comprises close to 150 standardised stations across Europe. The stations are directly supported by national funding and are called Station Networks. The ICOS Station Networks are coordinated and run by the ICOS National Networks, including 13 Member countries and one Observer country. The number of stations varies greatly between member countries. The age of the stations also varies, as some of them have been working for decades and others are newly established. All the stations have been substantially re-equipped to comply with ICOS standards.

Besides running the stations and working for labelling, the National Networks organise a number of other activities, such as a significant number of national or regional scientific events. These include conferences, training courses, workshops and annual meetings combined with seminars.

The stations in the National Networks operate in three distinct domains: Atmosphere, Ecosystem and Ocean. Each of these three fields has its own Monitoring Station Assembly (MSA) in which the Principal Investigators of the stations are represented to discuss, develop and improve the scientific and technical bases of the observations. The MSAs monitor, develop and improve the scientific and technical abilities of the station networks, working closely with ICOS Central Facilities, which include the Thematic Centres and Central Analytical Laboratories. The MSAs are also represented in the ICOS RI Committee by the Chair and Vice-Chair to communicate and discuss the views and recommendations of the stations' operators.

Within each domain (Atmosphere, Ecosystem, Ocean), a Thematic Centre coordinates the observations and supports the stations. In addition to the Thematic Centres, there are Central Analytical Laboratories (CALs) that provide gas analyses and calibration gases.

The Central Facilities coordinate and lead operations within their fields and process the data coming from the stations. They play key roles in specialised analyses, metrology and the technology watch, and support the measurement stations by offering spare instruments, training and technical assistance. The Central Facilities also have frequent interactions with one another for coordination, sensor interoperability and the standardisation of data archiving, data formats and processing methods. The Central Facilities are hosted by universities or research institutions in the Member countries.

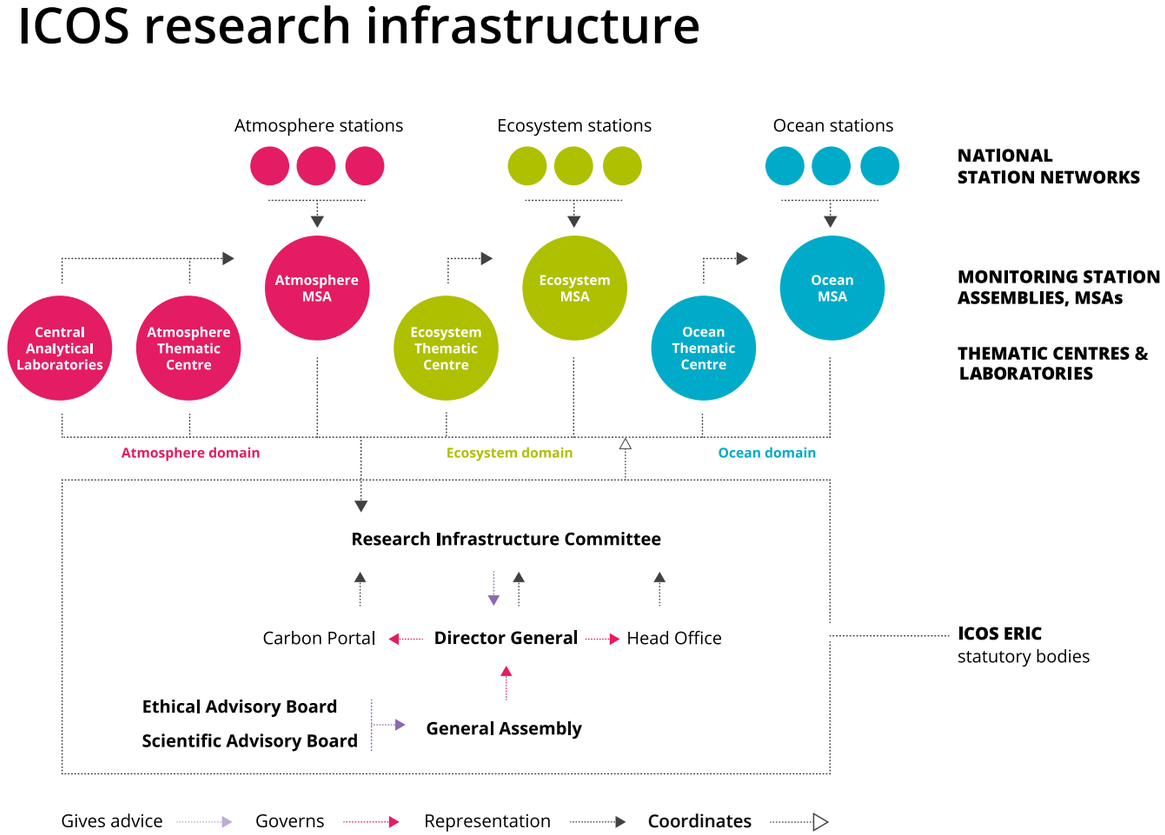
ICOS operations are coordinated by ICOS ERIC, which is a specific legal entity for European RIs created by the European Commission. ICOS ERIC consists of the Head Office, coordinating the RI operations, and the Carbon Portal, collecting and distributing ICOS data and derived products. In addition to coordinating, the Head Office is responsible for administration, management and development of the RI as well as for communication.

The Carbon Portal in turn acts as the platform for the observational data and elaborated data products of the ICOS RI. It is a 'one-stop shop' for all ICOS data products, a place where ICOS data, along with ancillary data, can be openly accessed by anyone. All ICOS data available in the Carbon Portal are quality controlled by the ICOS Thematic Centres.

ICOS ERIC is governed by its General Assembly. It appoints the Director General, who carries out the day-to-day management of ICOS ERIC and is responsible for the implementation of the decisions of the General Assembly. The Director General is responsible for managing the staff and activities of the Head Office and the Carbon Portal.

The representatives of the Head Office, Carbon Portal, Central Facilities and MSAs form a high-level advisory body called the RI Committee, which advises the Director General and the General Assembly on scientific and organisational matters concerning

Figure 1. ICOS RI governance and structure.



the RI. The ICOS RI Committee uses both face-to-face meetings and teleconferences to develop and discuss the ICOS RI's operations and strategic issues.

The General Assembly has established two external bodies to provide advice on scientific and ethical matters: the Scientific Advisory Board (SAB) and the Ethical Advisory Board (EAB). The role of the SAB is to give feedback and make recommendations to develop ICOS RI activities on the scientific level, to advise ICOS ERIC on objectives in achieving the scientific goals of the ICOS RI, to provide programmatic support by commenting on the overall science plans and directions as well as to analyse the scientific results and impact of the ICOS RI. The names of the members in SAB are listed in the Appendices. The role of the EAB is to advise and periodically report on ethical issues, such as scientific ethics, data-related ethical issues, discrimination issues or any kind of conflict of interest.

The overall structure of the ICOS RI is shown in Figure 1. A more detailed description of each operating part is given in Chapter 4 of this handbook.

ICOS RI financial principles and membership contributions

ICOS' financial structure follows the general policy of ESFRI: The RIs receive stable and sustainable national funding from their host countries to ensure their operations. In some countries, the funding has not been harmonised with the ICOS five-year planning period. Additionally, new developments and innovations are supported through external funding, for example, by the European Commission's Horizon funding for Research and Innovation.

ICOS has three levels of funding, mirroring the basic organisational structure of a distributed RI. The Member and Observer countries pay the *membership contribution* to ICOS ERIC. Additionally, ICOS ERIC receives *host premium contributions* from Finland, Sweden, the Netherlands and France. These cover the core operations of ICOS ERIC Head Office and Carbon Portal. Part of the membership contribution to ICOS ERIC is calculated based on the number and type of stations in the country. ICOS ERIC transfers this *station-based contribution* to the Central Facilities, which also receive *host or in-kind contributions* (80% of total funding) from their host institutions. National Networks receive funding from their governments or in-kind contributions from their host institutions.

Calculating Member and Observer contributions

Annual membership contributions to ICOS ERIC as well as host premium contributions by the hosting countries, cover activities that are of general benefit to the whole ICOS RI community: users, Members and Observers. ICOS ERIC statutes and the Internal Financial Rules of the ICOS RI set the principles for the calculation of the annual Member and Observer contributions to ICOS ERIC.

The General Assembly approves annual membership contributions every year. It determines the membership contributions of the potential intergovernmental organisations, which become Members or Observers on a case-by-case basis. The annual membership contribution of a Member or Observer country is based on the following three variables: Common basic contribution, Common Gross National Income (GNI)-based contribution and Station-based contribution.

The ICOS ERIC budget

The participating countries have agreed on the framework of the financial plan of the ICOS ERIC budget for the second five-year period of operations. The General Assembly has decided the Common basic and Station-based contributions for the whole five-year period 2020–2024. The amounts of Station-based contributions are shown in Table 1.

How Common Basic, Common Gross National Income and station-based contributions are calculated

The Common Basic contribution is a fixed number and it is based on the cost calculation done during the ICOS Preparatory Phase.

The Common GNI-based contribution for countries that have been members or observers already prior to 2020, the GNI share is calculated by dividing 50% of the common costs (€452,174) as follows:

The GNI-based payments are based on the three-year aggregate national GNI (according to the OECD) for Members or Observers prior to 2020, expressed as a percentage of the three-year aggregate GNI of all these ICOS RI Members and Observers.

The national GNI for each Member and Observer will be calculated for a period of three consecutive years and updated every five years or as otherwise directed by the General Assembly. The GNI values adopted by the General Assembly will be valid for a period of five financial years.

The statistics used to establish the scale of contributions shall be those available at the Head Office on 1 July before the ordinary autumn General Assembly meeting at which a new scale of contributions is presented.

From 2020 onwards, when a new country joins ICOS, the total ICOS ERIC revenue will increase with the fixed Common Basic Contribution and the GNI of the acceding country.

Membership contributions related to the number and type of stations joining the ICOS network are calculated based on information from the Members, Observers and ICOS Central Facilities and they are approved by the General Assembly. The current station contributions for Class 1 and Class 2 stations in the Atmosphere domain; Class 1, Class 2 and Associated stations in the Ecosystem domain; and Class 1 stations in the Ocean domain are listed in Table 1.

In addition to the host premium contributions, ICOS ERIC receives annually the common contribution which is related to the number of Members and Observers. The annual budget of ICOS ERIC is decided annually by the General Assembly. Table 2 shows the framework of the ICOS ERIC budget, which includes all components of membership contributions and the host premium contributions by the countries hosting the Head Office (Finland and France) and the Carbon Portal (Sweden and the Netherlands). The level of host premium contributions for the second five-year period of ICOS ERIC can be also seen in Table 2, in the column of budget estimate 2021.

Over the past five years, ICOS ERIC has also been very successful in getting funding from the EU Horizon 2020 funding instrument.

Table 1. Annual station-based contribution by station type. Atmosphere Class 1 stations receive a full set of analytical services from the Central Analytical Laboratories, including calibration services and radiocarbon analysis. Atmosphere Class 2 stations receive basic calibration services. Ocean station fee includes calibration services as well.

STATION TYPE	ANNUAL STATION CONTRIBUTION, €

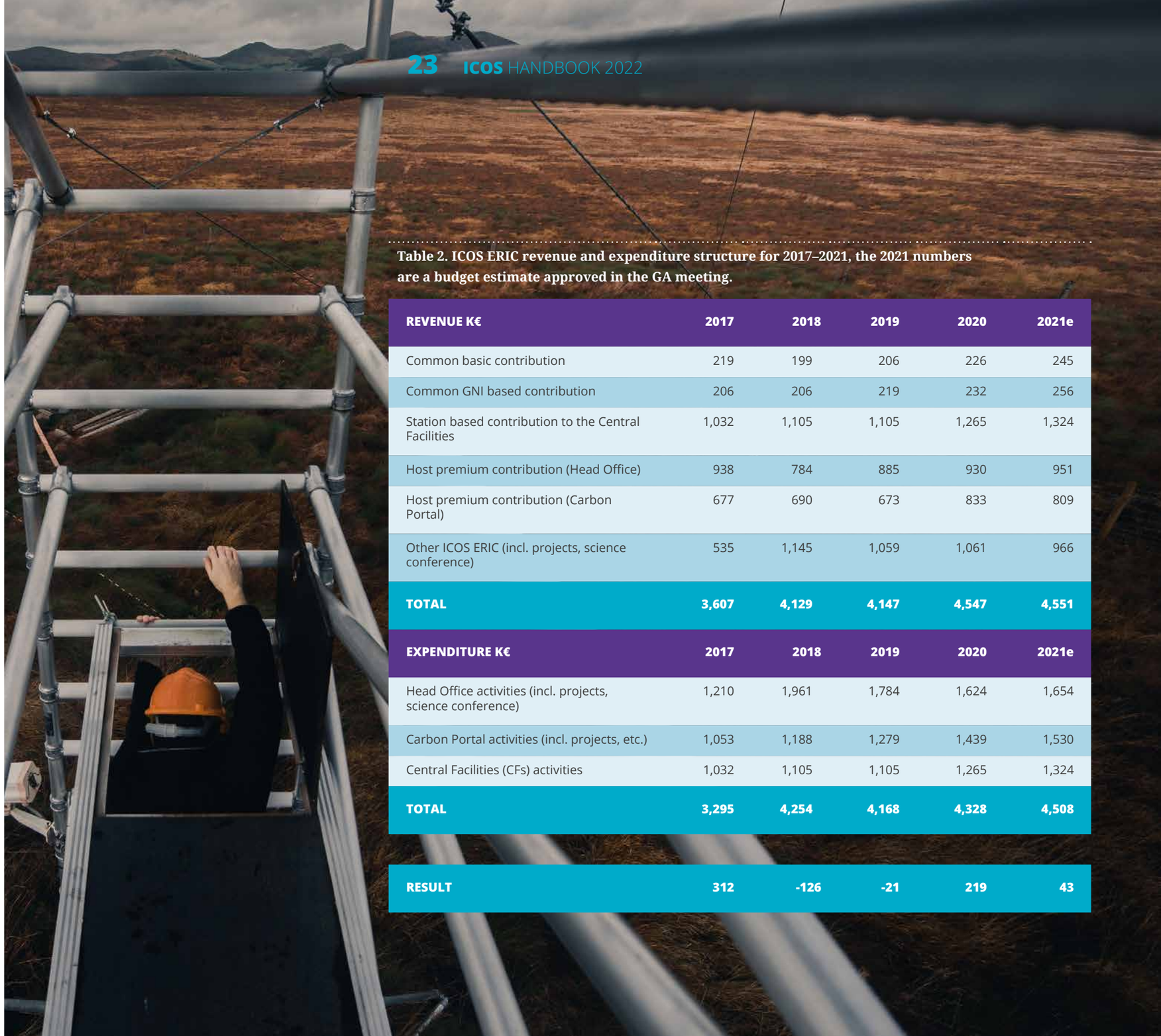


Table 2. ICOS ERIC revenue and expenditure structure for 2017–2021, the 2021 numbers are a budget estimate approved in the GA meeting.

REVENUE K€	2017	2018	2019	2020	2021e
Common basic contribution	219	199	206	226	245
Common GNI based contribution	206	206	219	232	256
Station based contribution to the Central Facilities	1,032	1,105	1,105	1,265	1,324
Host premium contribution (Head Office)	938	784	885	930	951
Host premium contribution (Carbon Portal)	677	690	673	833	809
Other ICOS ERIC (incl. projects, science conference)	535	1,145	1,059	1,061	966
TOTAL	**3,607**	**4,129**	**4,147**	**4,547**	**4,551**
EXPENDITURE K€	**2017**	**2018**	**2019**	**2020**	**2021e**
Head Office activities (incl. projects, science conference)	1,210	1,961	1,784	1,624	1,654
Carbon Portal activities (incl. projects, etc.)	1,053	1,188	1,279	1,439	1,530
Central Facilities (CFs) activities	1,032	1,105	1,105	1,265	1,324
TOTAL	**3,295**	**4,254**	**4,168**	**4,328**	**4,508**
RESULT	**312**	**-126**	**-21**	**219**	**43**

2 ICOS STATION LABELLING PROCESS: A quality assurance

Detailed labelling procedures for each domain are described in documents published on ICOS website at www.icos-cp.eu/about/join-icos/process-stations

The compliance of the stations to ICOS standards is of utmost importance to the users of ICOS data. To guarantee data reliability and quality across the stations, ICOS has designed a unique quality-assurance process called station labelling. The process has tight criteria that each station has to fulfil, both for the measurements at the stations and for data production. Once the station fulfils all the criteria set for an ICOS station, it receives an ICOS label as a guarantee that the data produced are of the highest quality.

To start the process, a country representative, Focal Point (a national coordinator) or General Assembly delegate officially announces the new station to the Head Office. Each ICOS station must be approved by its host institution and national government. However, before formally applying to become a labelled ICOS station, the interested party is advised to contact the appropriate Thematic Centre to discuss the station in terms of network design and station characteristics.

Benefits of ICOS labelling for the stations and their staff

- ICOS stations will take part in the latest developments of cutting-edge greenhouse gas measurement techniques and updated data-processing routines, which reduces the amount of work at the stations once they are labelled.
- ICOS stations will get substantial technical support for station operations in order to assure data quality. ICOS stations' staff will be involved in training activities organised by the Thematic Centres and Carbon Portal on the best and most updated practices for data acquisition and data use.
- The standardisation of the measurements and harmonised data processing, quality control and archiving are guaranteed through the Thematic Centres and the Carbon Portal data services to ensure the highest quality, comparability and credibility for the data.
- The provision of elaborated data products, such as advanced visualisations and flux maps in time and space, will increase the impact of the data.
- ICOS will provide support through contacts with equipment manufacturers and negotiates group prices for official ICOS stations.
- The global visibility of ICOS stations will increase due to the high-quality data provided and the large number of users. This will also have a strong positive effect on the host institution in terms of attractiveness.
- ICOS stations' data use will be professionally tracked and cited in peer-reviewed articles, which will increase the visibility of the station's staff and institution.
- ICOS stations will get support from the Head Office in searching for funding opportunities at the national and international levels using the well-developed ICOS brand in supporting proposals.

Steps towards ICOS station labelling

The ICOS station labelling process (Figure 2) takes several months and includes a testing period and a training to ensure familiarity with the ICOS methodology. When ICOS receives an application for a station to be labelled, the *first step* is to evaluate the site, the location of the measurement infrastructure and other characteristics of the station. These are evaluated by the Thematic Centres.

After the Director General has approved the station evaluation, the approved station is eligible to begin *step two*. This includes a thorough analysis of its compatibility with the ICOS measurement protocols and standards, measurement setup, data transfer and data quality. The Thematic Centres control the process and support the station's Principal Investigators in fulfilling the requirements for ICOS stations, and they also provide support for new incoming stations in the planning phase.

Finally, in *step three*, the General Assembly approves the station on the basis of the evaluation report prepared by the Thematic Centre and the recommendation of the Director General.

Figure 2. The steps of the ICOS station labelling process.

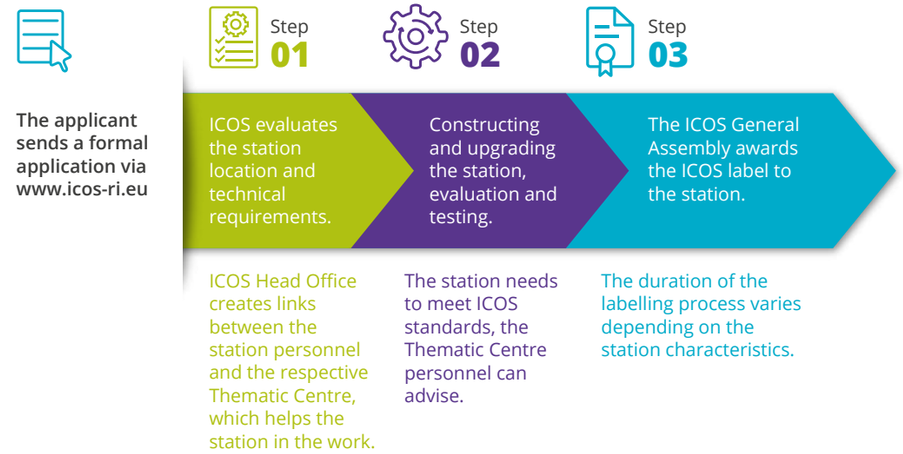
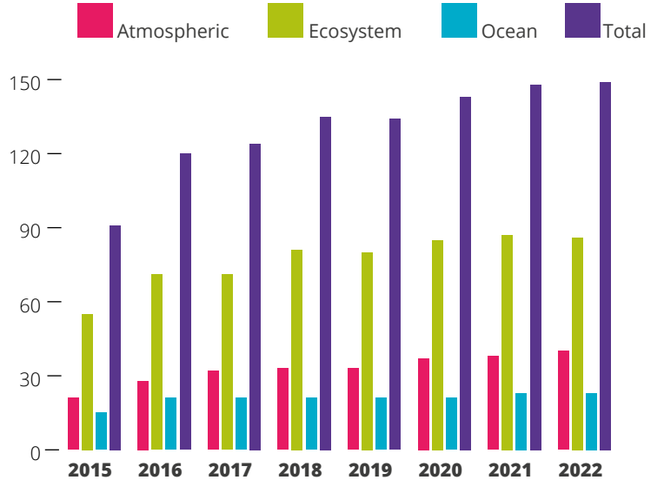


Figure 3. Number of ICOS stations in 2015–2022. The total number of stations was 149 in 2022.



After receiving the ICOS label, the station accepts the ICOS RI data policy and commits to be compliant with the station specifications, protocols and data-quality criteria used in its component (Atmosphere, Ecosystem, Ocean) under the authority of the Thematic Centre concerned. The ICOS Station network currently consists of close to 150 stations (Figure 3). These stations have officially been included in the ICOS RI by the Member and Observer countries. Two stations were brought into the network by the European Joint Research Centre through a specific contract. By March 2022, 92 stations had received an official ICOS label.

3 ICOS DATA: How they are produced and managed

ICOS data follow the so-called FAIR (Findable, Accessible, Interoperable, Reusable) principles. In practice, the FAIR principles aim at giving the user sufficient tools to understand the meaning of the data before and after downloading them. For this purpose, the ICOS Carbon Portal utilises linked open-data technology, which is a modern, advanced technology within the field of data management. It allows ICOS to distribute the data via internet links, which the user can simply click to view and/or download the data. It also makes machine-to-machine communication of data possible. Metadata and other descriptions are associated.

ICOS uses Creative Commons Attribution 4.0 International (CC BY 4.0) as its data-licence format. The licence gives the user extensive rights to use, redistribute and derive products from the data, under the condition that the data ownership is passed along and that proper attribution to the data provider is given. The user agrees to the licence when downloading the data.

To attach the data ownership, ICOS utilises Persistent Identifiers (PIDs) based on the Handle system for all the data objects. On top of these, it uses DataCite Digital Object Identifiers (DOIs) for datasets and collections. These uniquely identify each data object and can be cited, for example, in scientific publications. The PID is created automatically and immediately when the data are submitted, and mathematical encryptions are utilised to ensure the validity of the data. The PID is a World Wide Web address (URL: Uniform Resource Locator) that resolves into a so-called landing page where the metadata can be viewed or accessed by either humans or machines. In the case of the ICOS Carbon Portal, accessing the link will trigger the user-license acceptance check. The usage is counted at the download.

The whole process guarantees that the original data and downloaded data are exactly identical and are always available together with the associated metadata and that the user accepted the user licence. Other portals can use the PID and associated link to the data and give seamless access to the data object through the ICOS Carbon Portal.

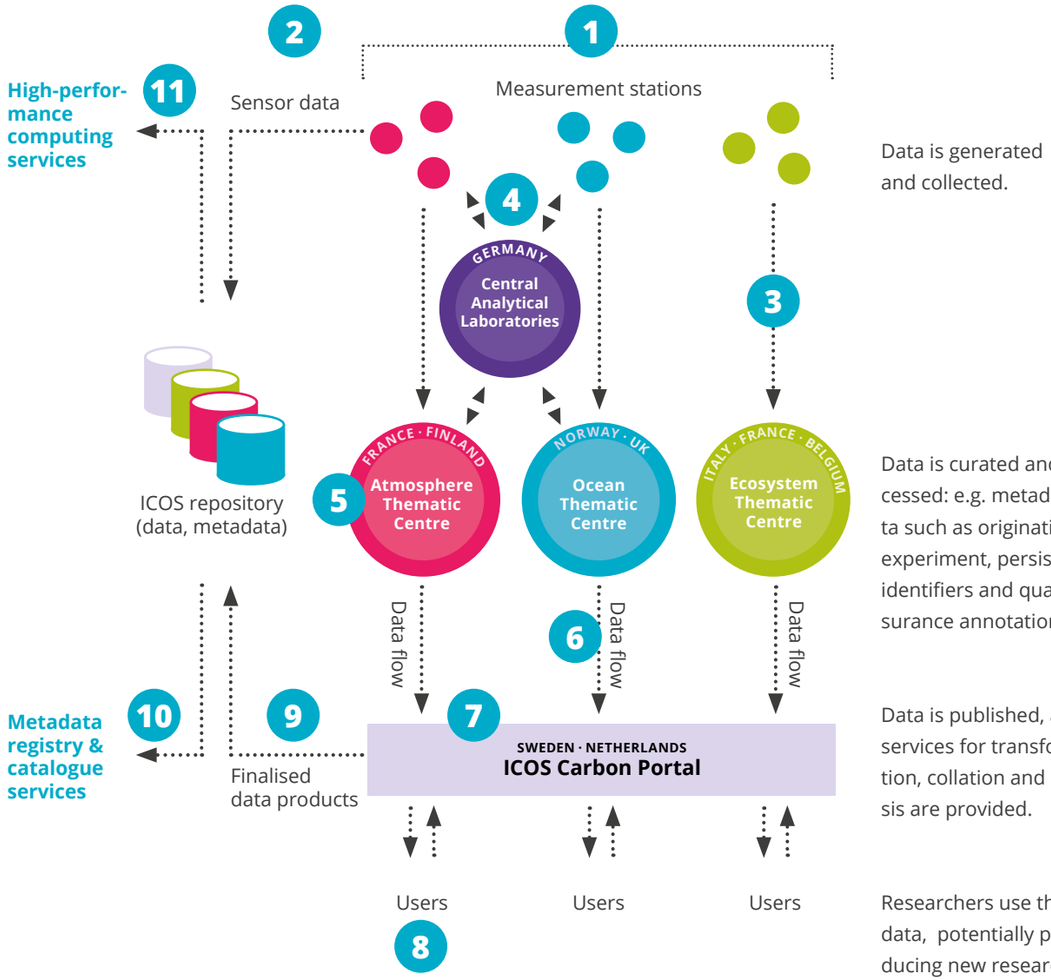
The ICOS data-production process

The following schematic diagram (Figure 4) shows the standardised ways of handling data within ICOS.

1. Data are collected at ICOS measurement stations. There are close to 150 sites in 14 countries, making up three networks of Atmosphere, Ecosystem and Ocean stations. Some sites or stations are equipped with up to 100 data-collecting instruments and sensors.

2. The 'raw' data are stored in a safe repository as soon as possible. Environmental observation data are very precious because if the data are lost, it is not possible to go back and remeasure. Therefore, copies of all the 'raw' data are transferred to safe, long-term storage at a trustworthy data centre. Typically, this is done within 24 hours of collecting the data.

Figure 4. Schematic diagram of the ICOS data-production process.



Data is generated and collected.

Data is curated and processed: e.g. metadata such as originating experiment, persistent identifiers and quality assurance annotations.

Data is published, and services for transformation, collation and analysis are provided.

Researchers use the data, potentially producing new research data.

3. The observation data are then passed on to the Thematic Centres for expert processing. Each station sends its sensor data to the relevant Thematic Centre – Atmosphere, Ecosystem or Ocean – for processing and quality control.

4. In addition to the three Thematic Centres, the Central Analytical Laboratories (CAL) are a part of the ICOS Central Facilities. CAL consists of Flask and Calibration Laboratory and the Central Radiocarbon Laboratory. They provide gas analyses and calibration gases.

5. The ICOS Thematic Centres take care of and process the observations following standardised procedures. At the Thematic Centres, the data are checked, quality controlled and, if needed, gap-filled. Some data types, for example, fluxes, require quite extensive processing. Finally, the data are aggregated into half-hourly or hourly averages.

6. Quality-controlled data are delivered by the Thematic Centres. When ready to be released, the finalised observation data are transferred to the Carbon Portal. How often new data become available varies, but the aim is to reduce as much as possible the time between collection and release.

7. The Carbon Portal is responsible for organising and taking care of all ICOS datasets. The Carbon Portal is the 'one-stop shop' for ICOS data products and offers advanced search, visualisation and downloading services. The portal is also responsible for all ICOS data management (such as assigning identifiers, DOIs, to make them easily cited), for tracking how ICOS data are used and for long-term archiving. Finally, it also provides user support.

8. Users can freely and openly access the ICOS data and may also contribute. Everyone who wants to access, view or download ICOS data products is welcome to do so. Any use of data should be properly referenced and acknowledged. Some ICOS data users, including atmospheric and ecosystem modellers, also use the Carbon Portal to distribute their research results. If you have a data product that is based on ICOS data, you are invited to make your data product available through the Carbon Portal.

9. All ICOS data products are safely stored in the ICOS repository. Copies of all data products that are handled by the Carbon Portal are stored in a safe, long-term manner in the ICOS repository. This also includes all metadata that are necessary to make sense of the data themselves. The repository is based on the B2SAFE service provided by the European Data Infrastructure (EUDAT) Collaborative Data Infrastructure (CDI), which is part of the European Open Science Cloud (EOSC). Data is replicated in the trusted repositories at two separate instances, one in Finland and one in Germany, next to the copy at the Carbon Portal and, in most cases, also at the Thematic Centres.

10. Descriptions of the ICOS data products and their contents must be easily found. ICOS is operating its own data catalogue, but we also share information about all the ICOS data products and how to access them with other data providers, including environmental and climate-data portals.

11. ICOS data can be effectively and quickly sent to other computing centres. Our collaboration with European e-infrastructure providers that are part of EOSC, such as EUDAT and EGI, makes it easy to transfer ICOS data to and from high-performance computing centres.

Data product levels

ICOS data are quantitative or qualitative attributes of variables or sets of variables that have been gathered using ICOS RI-recommended sensors at validated ICOS stations in an ICOS ERIC Member or Observer country. The measurements are standardised due to protocols mutually agreed upon by the Thematic Centres and Monitoring Station Assemblies (MSAs). The Principal Investigators of the ICOS stations are responsible for Quality Assurance at the station and for the first-order Quality Control of the data. Quality Assurance protocols, developed by the Atmosphere Thematic Centre (ATC), Ecosystem Thematic Centre (ETC) and Ocean Thematic Centre (OTC) in cooperation with the associated MSAs, must be used.

Level 0 data

Level 0 data, or so-called 'raw data', are information or objects directly obtained from human measurements or automated sensors that have not undergone any transformation. They may provide quantitative or qualitative information about physical variables of the environment and may be of various forms, such as images, text files or physical samples. For the sake of transparency and reproducibility, all ICOS Level 0 data are, in principle, available through the ICOS data licence.

Level 1 data

Level 1 Near Real Time data (L1_NRT): NRT data are generally developed for fast distribution using automated quality control within 24 hours of the measurement. NRT data are defined as a high-quality dataset that will be distributed in the default way through the Carbon Portal. These datasets have their own provenance metadata that describe the raw data used, the versions of the software and the scripts, the settings and the results of the automatic quality control.

Level 1 Internal or Intermediate Working data (L1_IW): Internal Working data are data that are generated as intermediate steps in the data processing of NRT or Level 2 data preparation, and for this reason they are not handled as persistent data and not shared outside the ICOS RI. Level 1 data are used for internal quality checks, as in the communication between Central Facilities and Principal Investigators. During the production of internal working data and following quality checks, important provenance information is generated that needs to become a part of the provenance metadata of Level 2 data.

Level 2 data

Level 2 data are the final, quality-checked ICOS RI dataset, published by the Central Facilities, to be distributed through the Carbon Portal.

Level 3 data

All kinds of products elaborated by scientific communities that rely partly or completely on ICOS data products are called Level 3 data. The Carbon Portal will provide resources to integrate and disseminate Level 3 products, which will be provided on a voluntary basis by the research community and/or, if agreed, by collaborative projects.

4 TECHNICAL DESCRIPTION: The operations of ICOS research infrastructure

The ICOS RI operates in three domains: Atmosphere, Ecosystem and Ocean. ICOS-related local cooperation is being led and carried out by a national coordinator who also serves as a so-called Focal Point in relation to ICOS ERIC. In many cases, an assistant has been nominated to share the workload and take care of practical matters. These tasks are usually performed as an in-kind contribution by one of the participating institutions.

Each observational network (Atmosphere, Ecosystem or Ocean) is coordinated and supported by a Thematic Centre through data services such as processing and quality control; training and technical assistance for site management; developing and testing new measurement sensors; instrument setups and methods; and developing new methods for data processing. France and Finland host the Atmosphere Thematic Centre (ATC), Italy, Belgium and France the Ecosystem Thematic Centre (ETC), Norway and the UK the Ocean Thematic Centre (OTC) and Germany the Central Analytical Laboratories (CAL).

The Central Facilities ensure that all data are treated and quality controlled with the same algorithms and are properly archived. The ATC, ETC and OTC receive online data from the ICOS stations, typically on a daily basis and in near-real-time. They interact with the Monitoring Station Assemblies, which consist of the stations' Principal Investigators, researchers and technicians, on matters related to the coordination and improvement of the ICOS National Networks.

In addition to having frequent interaction with one another, the Thematic Centres interact with research institutions and industrial partners to stimulate new measurement methods and sensor development for maintaining the state-of-the-art technology within the ICOS RI. The Central Facilities promote technology transfer, in particular towards local spin-off companies. Detailed descriptions of each Thematic Centre are given below.

Atmosphere observations

The greenhouse gas concentrations in the atmosphere integrate all natural and anthropogenic fluxes, atmospheric chemistry and transport processes. ICOS has established a network of tall towers, coastal and mountain stations where data on greenhouse gas concentrations in the atmosphere are collected. The ICOS Atmosphere network covers a large part of the European continent. The data feed, for example, informs inverse modelling approaches describing the sources and sinks of greenhouse gases.

How an Atmosphere station operates

Each ICOS Atmosphere station is an observatory established to continuously measure the dynamics in the concentration of greenhouse gases (CO_2, CH_4) and other trace gases (for example, CO), which are the result of regional and global surface fluxes as well as of complex atmospheric transport mechanisms.

A site chosen for installing an Atmosphere station will typically be representative of a footprint area of more than 10 000 km^2. The ICOS Atmosphere stations are equipped with commercially available instruments integrated into a digital control system run by ICOS ATC custom-made software. ICOS Atmosphere stations' modular character allows for various configurations, which manifest in two classes of stations: Class 1 and Class 2. Class 1 stations include complete equipment for measuring the full set of ICOS atmospheric parameters. Class 2 stations include equipment for measuring a pre-defined subset.

The addition of novel instruments to the existing ICOS Atmosphere station structure, for measuring additional gas species (for example, N_2O), or the replacement of the existing instruments with more advanced ones at a later date may occur. The mandatory parameters that each category of station in the ICOS Atmosphere network measures are listed in Table 3. The requirements for data quality and compatibility are the same for ICOS Class 1 and Class 2 stations.

In the future, additional stations with a more local footprint and with the same precision requirements as the main ICOS stations, for instance, stations located in areas of high local emissions (for example large cities), might be incorporated into the network. The estimated equipment cost and staffing requirements for the establishment and operation of ICOS Atmosphere stations are provided in Tables 4 and 5, respectively.

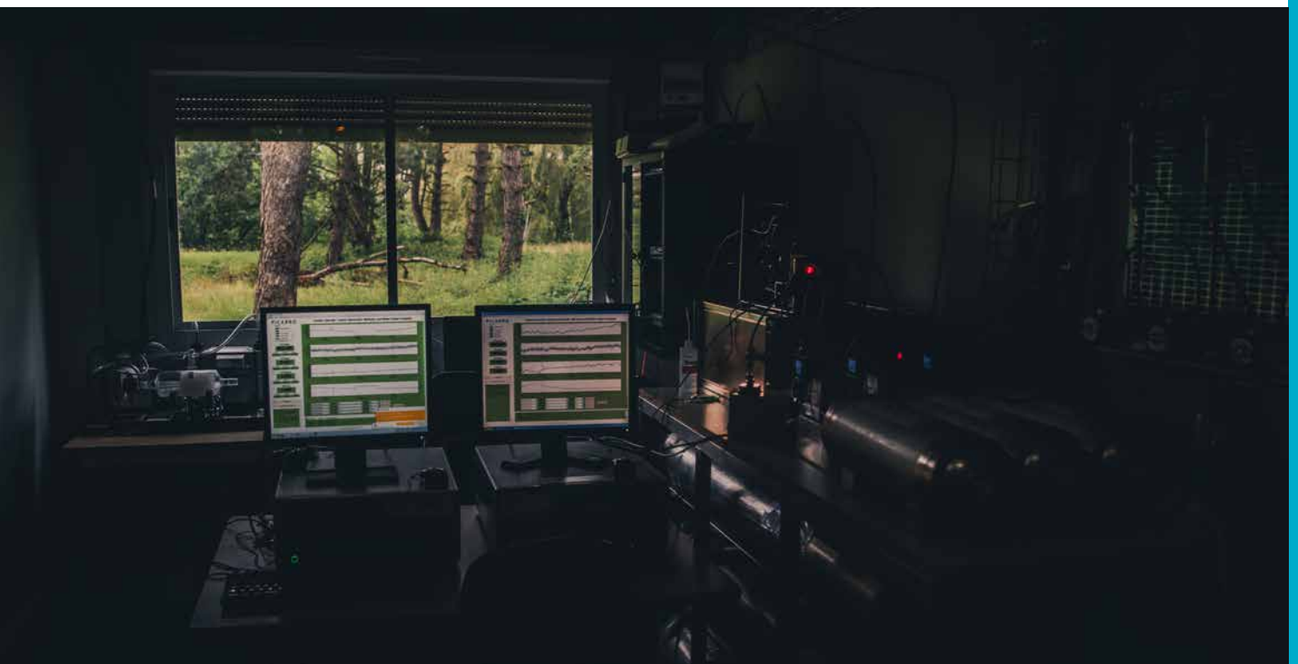


Table 3. List of parameters measured at ICOS Atmosphere stations.

CATEGORY	GASES, CONTINUOUS SAMPLING	GASES, PERIODICAL SAMPLING	METEOROLOGY, CONTINUOUS	EDDY FLUXES
Class 1 Mandatory parameters	CO_2, CH_4, CO: at each sampling height	CO_2, CH_4, N_2O, SF_6, CO, H_2, ^{13}C and ^{18}O in CO_2: sampled every three days at highest sampling height ^{14}C (radiocarbon integrated samples): at highest sampling height	Air temperature, relative humidity, wind direction, wind speed: at highest and lowest sampling height* Atmospheric Pressure Planetary Boundary Layer Height**	
Class 2 Mandatory parameters	CO_2, CH_4: at each sampling height		Air temperature, relative humidity, wind direction, wind speed: at highest and lowest sampling height* Atmospheric Pressure	
Recommended parameters***	^{222}Rn, N_2O, O_2/N_2 ratio CO for Class 2 stations	CH_4 stable isotopes, O_2/N_2 ratio for class 1 stations: weekly sampled at highest sampling height		CO_2: at one sampling height

* Atmospheric temperature and relative humidity recommended at all sampling heights.
** Only required for continental stations.
*** Recommended for its scientific value but support from ATC in terms of protocols, database, spare analyser will not be ensured as long as the parameters are not mandatory.

Table 4. Estimated equipment cost (k€) for the ICOS Atmosphere station. Sums depend on e.g. local taxes and markets.

CATEGORIES	DESCRIPTION	EQUIPMENT COST (k€)		
		Class 2	Class 1	Class 1 'Extended'*
Meteorological parameters	At 3 tower heights	10	10	10
CO_2, CH_4 continuous in situ measurement		55	55	55
CO continuous in situ measurement			+ 35 (in addition to CO_2/CH_4 cost)	+ 35 (in addition to CO_2/CH_4 cost)
CO/N_2O continuous in situ measurement				120
Periodic air sampling for CO_2, CH_4, N_2O, SF_6, CO, H_2 and CO_2 isotopes	Flask sampler with dryer + 100 flasks with shipment cases		65 + 25	65 + 25
Radiocarbon ($^{14}CO_2$) periodic sampling	Integrated sampler (NaCl)		10	10
Boundary Layer structure	Ceilometer or Lidar		30-80	30-80
^{222}Rn				30
CO_2 flux by eddy covariance	Fast in situ CO_2 analyser associated with a 3D wind sensor			40
Tubing, valve, pumps…		15-20	15-20	15-20
Calibration				
Tanks, pressure regulators…		10	10	10
Electrical and computing systems, data acquisition, storage and transmission, integration parts (indicative cost; prone to important variation depending on technical choice and station configuration)		10-50	10-50	10-50
TOTAL		**100–145**	**255–350**	**455–550**

* The column Class 1 'Extended' indicates equipment costs for Class 1 stations extended with some recommended but not mandatory parameters (see Table 3 for details).

Atmosphere Thematic Centre: Coordinating observations and processing data

The ICOS Atmosphere observations are coordinated by the ATC in close cooperation with the Atmosphere Monitoring Station Assembly and Central Analytical Laboratories. The ATC is composed of a data centre and a metrology lab and is complemented by an in situ station quality-control mobile lab (Figure 5). The ATC is coordinated and operated by the French Laboratoire des Sciences du Climat et de l´Environnement, supported by the Finnish Meteorological Institute.

The ATC has the following long-term objectives:

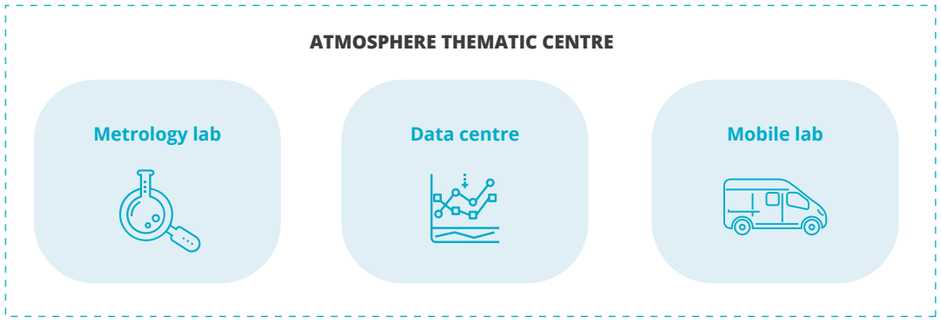
- Develop and operate the atmospheric data-processing chains, from the data transmission from stations to the routine delivery of the quality-checked data-stream used by modellers.
- Carry out a regular measurement-technology survey and analysis and enable the development of new sensors and their testing, for instance, through research and development programmes.
- Service the network with spare instruments, training and high-level technical assistance.
- Link the ICOS atmospheric data-collection programme with other ICOS Central Facilities within the framework of European and international monitoring programmes.

Table 5. Estimated annual manpower requirement (person month, PM) for the operation of an ICOS Atmosphere station.

CATEGORIES	ANNUAL MANPOWER (PM)		
	Class 2	Class 1	Class 1 'Extended'
Maintenance in situ gas analyser	1.5	1.5	2
Maintenance Meteo	0.5	0.5	0.5
Flask sampling and handling		1	1
Radiocarbon sampling		0.5	0.5
Maintenance Ceilometer or Lidar		1	1.5
Maintenance ^{222}Rn monitor			0.5
CO_2 flux			1.5
Station maintenance, data transmission, power etc.	1.5	1.5	1.5
TOTAL	**3.5**	**6**	**9**

* The column Class 1 'Extended' indicates equipment costs for Class 1 station extended with some recommended but not mandatory parameters

Figure 5. Structure of the ICOS Atmosphere Thematic Centre.



By meeting these goals, the ATC organises the Atmosphere network for optimal long-term operations. In the ATC, harmonisation in procedures and equipment with the appropriate Quality Assurance/Quality Control plan ensures the robustness and reliability of the collected atmospheric dataset.

The **ATC metrology lab** carries out regular measurement-technology surveys, tests and analyses for the greenhouse gas and isotope instruments of tomorrow. It facilitates the development of new sensors through research and development programmes at the national and international levels. The lab is the central labelling and training centre for ICOS atmospheric measurements, and it coordinates the development of atmospheric measurement protocols. It also provides high-level support to the network and loans replacement instruments in case of a major failure.

The **ATC data centre** develops and maintains in-house software to centrally process and quality control the data from ICOS Atmosphere stations. It provides near-real-time data products and other data products for stations' Principal Investigators.

The main task of the **ATC mobile lab** is to conduct quality control by parallel measurements at the Atmosphere stations. Its aim is to improve measurement compatibility and the development of competent quality assurance in the ICOS Atmosphere station network that ensures the credibility of the measurements. The mobile lab is hosted by the Finnish Meteorological Institute in Helsinki, Finland. The mobile lab operates a van equipped with state-of the-art analysers and standard gases, which are traceable to the WMO Central Calibration Laboratory and the ICOS CAL. Atmosphere station visits lasts for 1–2 months. During the visit, the standard gases of the station are cross-checked, and parallel monitoring of ambient air is conducted to validate the quality of the greenhouse gas monitoring of the station.

Central Analytical Laboratories ensure observation accuracy

The building of single central laboratories as ICOS CAL was based on earlier findings that differences between laboratories analysing flasks or producing calibration gases can substantially reduce the accuracy of a whole observational network. The aim of the CAL is to ensure the accuracy of ICOS atmosphere measurements.

The CAL is located in Germany and consists of two laboratories: the **Flask and Calibration Laboratory (FCL) in Jena**, which is hosted by the Max Planck Institute for Biogeochemistry, and the **Central Radiocarbon Laboratory (CRL) in Heidelberg**, which is operated by the Institute of Environmental Physics of the Heidelberg University.

The FCL does analyses of greenhouse gas concentrations and of other tracers that carry auxiliary information on the origin of the air samples (CO_2 stable isotope composition, O_2 level, additional gases). It also produces calibrated real air reference gases to ensure the compatibility of the ICOS atmospheric greenhouse gas observations with data from other global monitoring networks, such as WMO GAW, and provides support on the material involved. The tasks of the FCL are listed in Table 6.

The CRL quantifies the radiocarbon (^{14}C) content of CO_2 in air samples and develops methods to derive the fossil-fuel contribution to atmospheric CO_2 ($ffCO_2$). The tasks of the CRL are listed in Table 6.

Ecosystem observations

The ICOS Ecosystem observation network is a setup of instruments, usually on a tower, that measures the flux of relevant greenhouse gases, energy and momentum representing the local surface (for example, bare soil, vegetation, water) surrounding the measurement sites, typically within 100m–1km.

Additional measurements of ancillary parameters on air, plants and soil (or water body) are also made within this footprint area. The purpose of the ancillary measurements is to support process studies and to help in understanding the physical and biotic factors controlling the greenhouse gas fluxes. The ICOS Ecosystem observation network adheres to the monitoring principles of the Global Climate Observation System (GCOS) and Global Terrestrial Observing System (GTOS).

Central Analytical Laboratories use the following instrumentation:

- Isotope ratio mass spectrometer (Thermo Scientific MAT 253) and CO_2 extraction line for stable isotope analysis of atmospheric CO_2
- Isotope ratio mass spectrometer (Thermo Scientific DELTA V) for O_2/N_2 analysis of air samples
- Gas chromatograph (Agilent 7890A) for CO_2, CH_4, N_2O, H_2, CO and SF_6 concentration analyses in flask samples (detector types: FID, ECD, PDD, RGD)
- Oil-free compressor (Rix) combined with a Zero Air Generator and a depletion/spiking system for selective adjustment of tracers to produce real air calibration gases
- Cavity ringdown spectrometer (Picarro G2301) for CO_2 and CH_4 measurements
- Off-Axis Integrated Cavity Output Spectroscopy spectrometer (Los Gatos) N_2O/CO analyser
- FTIR Spectrometer (Ecotech Spectronus FTIR) for CO_2, N_2O, CO and CH_4 analyses
- ^{14}C low-level gas proportional counting facilities for high-volume samples
- Semi-automated CO_2 extraction and graphitisation devices to produce graphite targets for subsequent AMS analysis

Table 6. List of the specific tasks of the Flask and Calibration Laboratory (FCL) and the Central Radiocarbon Laboratory (CRL).

TASKS OF THE FCL		
Flask samples	**Standard gases**	**Quality control**
• Analysis of the following parameters in air samples from the ICOS stations: trace gas concentrations (CO_2, CH_4, N_2O, H_2, CO, SF_6) stable isotopes of CO_2 ($\delta^{13}C$ and $\delta^{18}O$) • O_2/N_2 ratio • Initial conditioning of air-sample containers (flasks) to achieve long-term stability of the CO_2-$\delta^{18}O$ signature • Routine leak test of flasks • Sampler development and production	• Production of real air reference gases for ICOS atmosphere stations and observing ships • Initial conditioning of high-pressure cylinders • Calibration of reference gases (CO_2, CH_4, N_2O, CO) relative to the established WMO scales (maintained by the Central Calibration Laboratory at NOAA-ESRL) • Provision of standard gases as temporary replacement sets for stations and for round-robin inter-comparisons	• Maintenance of comprehensive internal quality-assurance procedures • Active maintenance of the link to the WMO scales by regular recalibration of ICOS lab standards by the WMO Central Calibration Laboratory • Organisation of an ongoing international comparison programme
TASKS OF THE CRL		
$^{14}CO_2$ analysis	**ICOS network support**	**Fossil fuel CO_2 estimation**
• Analyses of up to 500 samples per year via gas proportional counting • Extraction of CO_2 from flask and high-volume samples with subsequent graphitisation for AMS analysis for up to 1,500 samples per year • Comprehensive quality management from an internal to an international level	• Serve the atmospheric ICOS sampling network with CO_2-free NaOH solution for high-volume CO_2 absorption • Build integrated, high-volume $^{14}CO_2$ samplers for the conventional gas-counting method • Develop new $^{14}CO_2$ sampling equipment	• Operation of an atmospheric pilot station measuring all major greenhouse gases and isotopes in CO_2 as well as ^{222}Rn progeny • Assessment of new sampling strategies or surrogate tracers

Interoperability among Central Analytical Laboratories, Thematic Centres and Observation networks

Sample logistics

The role of the FCL and CRL is the analysis of air samples collected at ICOS stations. The FCL serves the Atmosphere network in maintaining their sampling equipment (flasks). CO_2-free NaOH solution is supplied to Class 1 stations by the CRL for radiocarbon sample collection. Sample logistics and sampling information will be handled centrally in the CAL database. The CAL database system documents the sample processing, starting with collection at the sites, sample preparation, analysis steps and sample container maintenance.

Data processing

The analysis of several thousands of samples per year on various instruments in the FCL and CRL generates a large amount of raw data that need to be processed, evaluated and archived. For this, an elaborate database system, suited for the task, is being further developed by the FCL and the CRL. The CAL database application has an interface to the ATC database, providing the analysis results and comprehensive metadata information for all samples. The data management strategy allows for measurement data to be reprocessed at any time should calibration corrections be necessary by hindsight.

How an Ecosystem station operates

ICOS Ecosystem stations are based on instrumentation, partly commercial, embedded into an integrated system for ecosystem monitoring. As the ecosystem observing involves human intervention in field activities (such as plant and soil sampling), an ICOS Ecosystem station follows a set of rigorously standardised protocols developed for field ecosystem measurements.

The ICOS Ecosystem station network includes two classes of Ecosystem stations, referred to as Class 1 (complete) and Class 2 (basic) stations. They differ in costs of construction, operation and maintenance due to the reduced number of variables measured at the Class 2 stations. This strategy enhances flexibility and ensures a high level of participation. A list of variables that each category of stations in the ICOS Ecosystem network measures is presented in Table 7.

The estimated cost and workforce required for operating an Ecosystem station are provided in Tables 8, 9 and 10. The costs reported include all the investments and are calculated on the basis of a seven-year lifetime of all the equipment except the tower.

There is a possibility of establishing ICOS Ecosystem station-associated sites. The requirement is to submit at least one full year of data, which must include a set of key variables with full descriptions and meta-information, with the acceptance of the ICOS data policy. The data from these stations are processed within the ETC database. The associated sites receive an ICOS-associated status.

Table 7. List of variables that are collected at the various ICOS Ecosystem stations (Class 1 and Class 2) for the various ecosystem types.

VARIABLES	FOREST	GRASS-LAND	CROP-LAND	WET-LAND*	MA-RINE**	LAKES**
CO_2, H_2O and H fluxes (eddy covariance, including profile for storage)	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2
CH_4 and N_2O fluxes (eddy covariance, including profile for storage)	1	1	1	1	1	1
Air H_2O concentration	1	1	1	1	1	1
Incoming, outgoing and net SW and LW radiations	1 & 2	1 & 2	1 & 2	1 & 2	1	1
Incoming SW radiation (high quality)	Fac	Fac	Fac	Fac	Fac	Fac
Incoming PPFD	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2
PPFD below canopy + ground reflected	Fac	Fac	Fac	N.R.	N.R.	N.R.
Outgoing PPFD	1 & 2	1 & 2	1 & 2	1 & 2	Fac	Fac
Diffuse PPFD and/or SW radiation	1	1	1	1	Fac	Fac
Spectral reflectance	Fac	Fac	Fac	Fac	Fac	Fac
Soil heat flux	1 & 2	1 & 2	1 & 2	1 & 2	N.R.	N.R.
Air temperature and humidity profile	1 & 2	1 & 2	1 & 2	1 & 2	Fac	Fac
Backup meteo station (TA, RH, SW_IN, precipitation)	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2
Total high-accuracy precipitation	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2
Snow height	1 & 2	1 & 2	1 & 2	1 & 2	Fac	Fac
Soil water-content profile	1 & 2	1 & 2	1 & 2	1 & 2	N.R.	N.R.
Soil temperature profile	1 & 2	1 & 2	1 & 2	1 & 2	N.R.	N.R.
Air pressure	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2
Trunk and branches temperature	Fac	N.R.	N.R.	N.R.	N.R.	N.R.
Water-table depth	1 & 2	1 & 2	1 & 2	1 & 2	N.R.	N.R.
Tree diameter (continuous)	1	N.R.	N.R.	N.R.	N.R.	N.R.
Phenology/camera	1	1	1	1	N.R.	N.R.
Soil CO_2 automatic chambers	1	1	1	1	1	1
CH_4 and N_2O fluxes by automatic chambers	1	1	1	1	1	1
Wind speed and wind direction (additional to 3D sonic)	1	1	1	1	1	1
GAI	1 & 2	1 & 2	1 & 2	1 & 2	N.R.	N.R.
Above-ground biomass	1 & 2	1 & 2	1 & 2	1 & 2	N.R.	N.R.
Soil carbon content	1 & 2	1 & 2	1 & 2	1 & 2	N.R.	N.R.
Litterfall	1	1	1	1	N.R.	N.R.
Leaf nutrients content	1 & 2	1 & 2	1 & 2	1 & 2	N.R.	N.R.
Soil-water N content	Fac	Fac	Fac	Fac	N.R.	N.R.
DOC concentration	Fac	Fac	Fac	Fac	N.R.	N.R.
C and N import/export by management	1 & 2	1 & 2	1 & 2	1 & 2	N.R.	N.R.
Oxygen and pCO_2 surface concentration	N.R.	N.R.	N.R.	Fac	2	2
Oxygen, pCO_2 and pN_2O concentration profile	N.R.	N.R.	N.R.	Fac	1	1
Salinity	N.R.	N.R.	N.R.	N.R.	1 & 2	N.R.
Wave properties	N.R.	N.R.	N.R.	N.R.	Fac	Fac
Water-temperature profile	N.R.	N.R.	N.R.	N.R.	1	1
Management and disturbances information	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2

Fac = Facultative variable; N.R. = Not Relevant for the ecosystem.
* Wetland includes all distinct water-inundated or saturated ecosystems according to Joosten and Clark 2002.
** List of variables for Lake, Marine and Urban sites under discussion.

Table 8. Estimated equipment cost (k€) for the ICOS Ecosystem station. Sums depend on e.g. local taxes and markets.

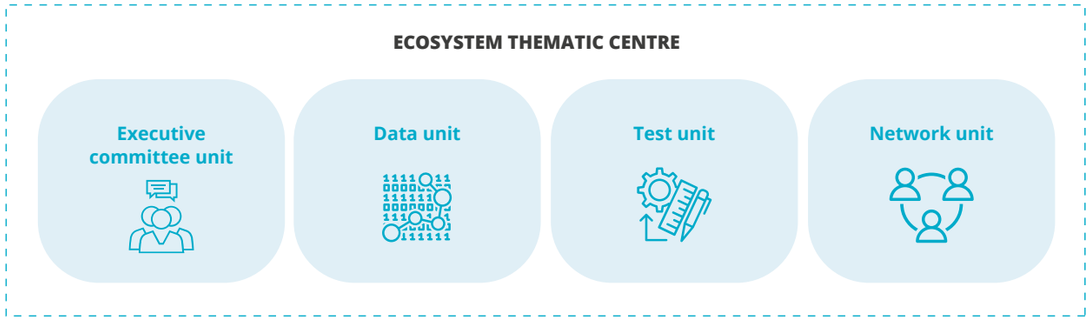
CATEGORIES	FOREST		CROP		GRASS		MIRE	
	Class 1	Class 2	Class 1	Class 2	Class 1	Class 2	Class 1	Class 2
Infrastructure	30-120	30-120	10-25	10-25	10-25	10-25	15-35	15-35
CO_2, H_2O energy EC	30-40	30-40	30-40	30-40	30-40	30-40	30-40	30-40
Storage CO_2 and H_2O	20-30	20-30	0-10	0-10	---	---	---	---
CH_4 EC	50-70	---	50-70	---	50-70	---	50-70	---
N_2O EC	100-150	---	100-150	---	100-150	---	100-150	---
Storage CH_4	25-50	---	---	---	---	---	---	---
Storage N_2O	25-50	---	---	---	---	---	---	---
Radiations	10-30	6-28	10-15	6-12	10-15	6-12	10-15	6-12
Soil meteorology	15-25	10-15	15-25	10-15	15-25	10-15	10-20	8-12
Basic meteo	15-25	13-22	15-25	13-22	15-25	13-22	15-25	13-22
Precipitations	4-7	4-7	4-7	4-7	4-7	4-7	4-7	4-7
Phenology-Camera	2-3	2-3	2-3	2-3	2-3	2-3	2-3	2-3
Soil CO_2 automatic chambers	50-75	---	50-75	---	50-75	---	50-75	---
Ancillary data	10-15	4-10	10-15	4-10	10-15	4-10	6-15	6-10
Tree diameter	4-5	---	---	---	---	---	---	---
Leaf nutrients content								
Soil carbon content								
Management, disturbances, C & N import and export								
Site characterization								
Dataloggers, other costs	10-25	6-20	10-25	6-20	10-25	6-20	10-25	6-20
TOTAL	**400-720**	**125-295**	**306-485**	**85-164**	**306-475**	**85-154**	**302-480**	**90-161**

Table 9. Estimated annual manpower requirement (PM) and maintenance cost (k€) for the operation of an ICOS Ecosystem station. Sums depend on e.g. local taxes and markets.

CATEGORIES	FOREST		CROP		GRASS		MIRE	
	Class 1	Class 2	Class 1	Class 2	Class 1	Class 2	Class 1	Class 2
Installation (PM)	3-10	3-8	2-5	1.5-4	2-5	1.5-4	2-5	1.5-4
Maintenance and sampling (PM)	24-36	18-30	22-34	18-30	24-36	20-34	24-36	15-24

CATEGORIES	FOREST		CROP		GRASS		MIRE	
	Class 1	Class 2	Class 1	Class 2	Class 1	Class 2	Class 1	Class 2
Maintenance costs	3-6	3-5	8-12	6-10	8-12	6-10	8-12	6-10

Figure 6. Structure of the ICOS Ecosystem Thematic Centre.



Ecosystem Thematic Centre: Coordinating observations and processing data

The ICOS Ecosystem observations are coordinated by the ETC. The ETC offers continuous support to the Ecosystem stations and organises additional training activities. It performs the centralised data processing and quality control and provides technical assistance to the stations. The ETC collaborates closely with the Ecosystem MSA and the broader scientific community to develop and test new data processing methods, measurement techniques and instruments to evaluate their potential use and implementation in the Ecosystem network. As part of the labelling process, the ETC evaluates the quality of the Ecosystem stations before they are included in the ICOS Ecosystem station network. The ETC manages the international collaborations of the Ecosystem network to increase its visibility and oversees the activities that enhance the data interoperability across different terrestrial Ecosystem networks and Research Infrastructures.

The ETC processes the data on net ecosystem fluxes and their components, carbon stocks and ancillary data. Diverse processing hierarchies are used for the production of the various data levels. Near-real-time datasets are released for data users that need fast access to recent data and for continuous data quality control. Ancillary information about the stations (for example: vegetation and soil characteristics; disturbances; management) are processed, often starting from raw measurements, to guarantee a high standardisation between the various stations. All the data and metadata are delivered to the Carbon Portal for further user distribution.

The ETC is coordinated and operated by the Euro-Mediterranean Centre on Climate Change (CMCC) in collaboration with the University of Tuscia (UNITUS) in Viterbo, Italy, the University of Antwerp (Research group Plants and Ecosystems, PLECO) in Antwerp, Belgium and the French National Research Institute for Agriculture, Food and Environment (INRAE), France.

Although the ETC has been organised to maximise the interchangeability of the members to increase its robustness and share its competencies, the groups involved have distinct fields of expertise and main responsibilities. The Italian partners, UNITUS and CMCC, coordinate the ETC and the processing of ecosystem fluxes and meteorological data, the University of Antwerp is responsible for the ancillary vegetation data collection and treatment, while INRAE receives, analyses and stores the soil and vegetation samples. The ETC is organised in four main units with specific tasks (Figure 6).

Unit 1: The Executive Committee Unit's main tasks include communication and interaction with the ICOS community and other Central Facilities. The unit also organises annual assessments of ETC operations and plans its medium- and long-term activities. It is also responsible for the international collaborations.

Unit 2: The Data Unit's main tasks include Level 2 and NRT data production and metadata collection as well as automatic data quality assistance, quality control and processing. The unit shares, distributes and archives data and develops tools for data exploration and validation. This unit also maintains an alert service in case of data problems and inconsistencies.

Unit 3: The Test Unit's main tasks include the evaluation of new sensors and prototypes and the development of new processing and quality control methods. The unit is responsible for interactions with instrument manufacturers and research centres.

Unit 4: The Network Unit's main tasks include providing assistance to the ICOS Ecosystem stations, evaluation of station performances and the labelling activities. The unit organises training sessions for site managers and technicians and forms workgroups for protocol development. This unit also analyses soil and vegetation samples and takes care of their storage.

Ocean observations

ICOS provides long-term observations from 23 Ocean stations in eight countries, monitoring carbon uptake and fluxes in the North Atlantic and the Nordic, Baltic and Mediterranean Seas. The measuring methods include sampling from research vessels, moorings, buoys and commercial vessels, so called Ships of Opportunity (SOOP). They all have been equipped with state-of-the-art carbonate system sensors.

The ICOS Ocean observation network is also enhancing and actively seeking, developing and exploring new methodologies. For example, in addition to the core platforms mentioned above, the ICOS Ocean network cooperates with the wider community to develop new sensors for the carbon system for autonomous platforms, such as Argo floats and gliders, to provide better coverage of more remote areas. It also works with the hydrographic community to provide full-depth carbon observations.

The linear coverage along ship tracks is integrated with satellite-based observations and modelled data to provide extrapolation across the surface of the ocean. The satellite data are also used to assist in the interpolation of the data between passages of ships. Carbon flux estimates are based on ships' and satellite measurements of the surface temperature, the winds and the output of real-time ocean forecasting models. This provides the comprehensive assessment that is required to monitor and understand the present state of the oceans. ICOS Ocean observations aim to better understand the complex interplay between oceans and the atmosphere.

How an ocean station operates

ICOS Ocean stations are based on instrumented Ships of Opportunity (SOOP) and Fixed Ocean Stations (FOS). The SOOP are either research vessels or commercial ships operating on regular, repeated ship routes on the European shelf and marginal seas and those of cargo vessels on open ocean routes.

The FOS are fixed sites in the ocean. They are able to provide near-real-time data that also might contain information from greater depths, for example, about temperature anomalies. FOS observations are recorded by means of moorings. These platforms require visits from well-equipped research vessels, preferably 2–12 times per year. Coastal FOS can be equipped with shore-based towers for direct flux measurements called Marine Flux Towers (MFT). Such mixed stations, by nature, serve both the Ocean and Ecosystem community. FOS can also be fixed sites in the ocean, from where primarily discrete water samples are collected, which is less common.

The SOOP and FOS are equipped with a suite of automated instrumentation to measure ocean-surface pCO_2, sea surface temperature, salinity and related variables. On SOOP lines, measurements are repeated along the same transects at intervals of days to months; they cover only the marine surface.

SOOP and MFT typically measure semi-continuously, while the temporal coverage of FOS ranges from semi-continuous to annual. For each category of Ocean stations, ICOS defines two classes of stations according to the set of parameters measured (see Tables 10a, b). The labelling of ICOS Ocean stations is based on two key motivations: 1. Quantifying air-sea CO_2 fluxes and 2. Assessing variability and drivers of the carbonate system. The resulting uncertainty requirements for the various variables can be related to the motivations.

The current Ocean station setup consist of 13 SOOP lines and 10 FOS where one of the FOS has a Marine Flux Tower connected to it. The coverage includes repeated East–West and North–South transects of the Atlantic Ocean, Baltic Sea and the North Sea, as well as a transect sampling that reaches out to the Barents Sea and all the way to the Arctic Ocean. FOS are situated in the Baltic, the Atlantic Ocean, as well as in the Mediterranean Sea.

Table 10a. List of required variables measured at ICOS SOOP stations.

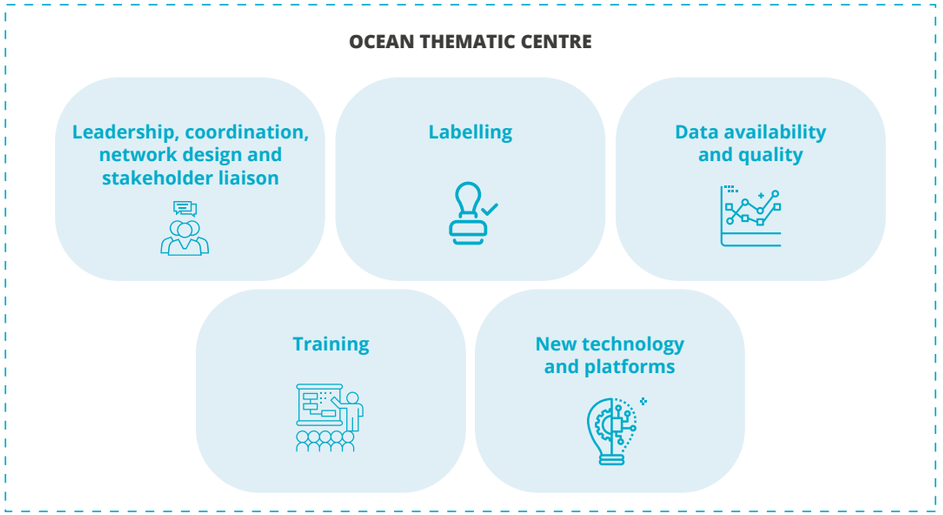
VARIABLE	FREQUENCY	ACCURACY	REQUIRED FOR CLASS
Sea surface fCO_2	Quasi-continuous	± 2 µatm	2
Intake temperature (SST)	Continuous	± 0.05 °C	2
Equilibrator temperature	Continuous	± 0.05 °C	2
ΔT (Intake/Equilibrator temperature difference)	Continuous	< 1.5 °C (normal) < 3 °C (ice-edge)	2
Water vapour pressure*	Continuous	± 0.5 mbar	2
Equilibrator pressure	Continuous	± 2.0 mbar	2
Atmospheric pressure/sea level pressure	Continuous	± 1.0 mbar	2
Sea surface salinity (SSS)	Continuous	± 0.1 PSU	2
Dissolved oxygen	Continuous	± 2%	1
Total alkalinity (TA)**	***	± 10 µmol kg^{-1}	1
Dissolved inorganic carbon (DIC)**	***	± 5 µmol kg^{-1}	1

* If the analysed headspace gas is not dried completely prior to measurement.
** At least one of these variables must be provided.
*** The frequency of these additional variables will be decided on during the labelling process based on the area where the station is operating.

Table 10b. List of required variables measured at ICOS FOS stations with continuous/quasi-continuous measurements.

* At least one of these variables must be provided.
** The frequency of these additional variables will be decided on during the labelling process based on the area where the station is operating.
*** pH (together with TA or DIC) is only required for validation of the pCO_2 data and is not needed as a regular variable. pH should not be used together with pCO_2 to calculate the full carbonate system due to high resulting uncertainty. OTC will assist with the supply of sampling material and measurement of pH samples.
**** At least two out of the three dissolved nutrients nitrate (NO_3), phosphate (PO_4), and silicate ($Si(OH)_4$) must be provided.
***** The accuracy refers to samples without conservation. If conservation is used (freezing is the most used method) the accuracy might decrease, especially for silicate.

Figure 7. Structure of the ICOS Ocean Thematic Centre.



The Executive Unit is in charge of leadership, coordination of Ocean Thematic Centre, network design and stakeholder liaison. OTC leadership is a shared responsibility between the OTC director and the deputy director.

The Labelling Unit is in charge of the station labelling process. The unit's task is also the development of station labelling reports. The reports include the evaluation of the stations undergoing the labelling procedure.

The Data Unit is in charge of the data collection, availability and quality. The unit tracks the data collection, flow, processing, quality and availability for all the stations that are part of the ICOS Ocean network. They ensure the contribution to the relevant global data collections, as well as prompt actions in order to solve potential critical situations.

The Training Unit's task is to optimise and standardise performance of the network instrumentation and calibration. They provide guidance, technical support for installations at individual stations and organise training events for the ICOS Ocean community.

New Technology and Platforms Unit is in charge of new sensors and new platforms. Its task is to invite early adopters as collaborators or partners in future research grants to explore new technologies.

Table 11a. Estimated investment cost (k€) for an ICOS Ocean station. Sums depend on e.g. local taxes and markets.

CATEGORIES	DESCRIPTION	SOOP		FOS		
		Class 1	Class 2	Class 1	Class 2	Flux tower
CO_2 in situ measurements	UW equilibrator based system	100	100			
CO_2 in situ measurements	Membrane based system			35	35	
LICOR Sensor	To accompany Equilibrator	25	25			
Temperature, Salinity	Essential Additional Data	40	40	40	40	
Dissolved Oxygen		20		10	10	
Nutrients				40		
Deployment platform	Buoy, highly variable			80	80	
CO_2 flux measurements (incl. Tower, data aquisition)						60
One off cost to visit the station for set up and data aquisition		20	20	20	20	20
Total Alkalinity/Dissolved Inorganic Carbon (TA/DIC)		35				
Tubing, valve, pumps…		10	10	10	10	
Calibration of sensors on deployment		10	10	10	10	
Tanks, pressure regulators…		5	5	5	5	
Capital cost of electrical and computing systems, data acquisition, storage and transmission, integration parts (indicative cost; prone to important variation depending on technical choice and station configuration)		20	20	20	20	
TOTAL		**285**	**230**	**270**	**230**	**80**

NB Flux tower estimates assume full flux tower is in place already

Table 11b. Estimated annual manpower requirement (PM) and maintenance cost (k€) for the operation of an ICOS Ocean station. Sums depend on e.g. local taxes and markets.

CATEGORIES	SOOP		FOS		
	Class 1	Class 2	Class 1	Class 2	Flux tower
Maintenance (pCO_2, Sal, Temp) (PM)	1	1	1	1	
Maintenance DO (calibration included) (PM)	1		1	1	
Maintenance (TA/DIC) (PM)	1	1			
Maintenance CO_2 (PM)	1	1	1	1	4
Maintenance nutrients (calibration included) (PM)			1		
Sampling/analysis (PM)	3	3	3	3	
Station maintenance, data transmission, power etc. (PM)	3	3	3	3	6
Data reduction, validation and QC (PM)	3	3	3	3	3
TOTAL (PM)	**13**	**12**	**13**	**12**	**13**
Maintenance CO_2 (k€)	1	1	1	1	5
Maintenance Temp, Sal (k€)	1	1	1	1	
Maintenance DO (calibration included) (k€)	1		1		
Maintenance nutrients (calibration included) (k€)	1	1	1		
Sampling/analysis (k€)	5	5	5	5	
Station maintenance, data transmission, power etc. (k€)	5	5	5	5	10
Consumables (pCO_2, Sal, Temp)	5	5	5	5	
Consumables DO (calibration included)	5		5	5	
Consumables (TA/DIC)	5				
Travel and subsistence for Station maintenance	10	10	10	10	
TOTAL MAINTENANCE COSTS (K€)	**39**	**28**	**34**	**32**	**15**

Carbon Portal

The ICOS Carbon Portal offers access to research data as well as to easily accessible and understandable science and education products. The Carbon Portal is hosted by the University of Lund in Sweden and Wageningen University in the Netherlands and is located in Lund. All measurement data available on the Carbon Portal are quality controlled through the ICOS Thematic Centres: the ATC, ETC, OTC and the CALs. The Carbon Portal has the ability to address all the requirements stemming from those aspects, including data security, enforcement of the ICOS data policy and user-friendly (and machine-friendly) internet-based and other computer-network-based interfaces.

The Carbon Portal is an integrative access point for all ICOS users and stakeholders, ranging from experts to the general public, and it supports standardised data-exchange protocols and techniques. Organising the long-term archiving of ICOS data products, with the aim of guaranteeing their safe storage and future access (including after a possible cessation of the research infrastructure itself), is an important task of the Carbon Portal. The Carbon Portal's activities and features are as follows:

Long-term data archiving and (back-up) storage

An important task of the ICOS Carbon Portal is to organise the long-term archiving of ICOS data products, with the aim of guaranteeing both safe storage and future access long after the cessation of the RI itself. This activity complements the data storage and backups routinely performed by the Thematic Centres. Decisions regarding the archiving strategy used are to be taken by the ICOS RI in consultation with the Thematic Centres and MSA Principal Investigators.

Data mining, data extraction, collocation

In order to facilitate the interactions of a wide spectrum of user categories, the Carbon Portal acts as the main access platform for any and all parties interested in ICOS data products. In addition, the Thematic Centres may operate their own data-access interfaces, provided authentication control is given through the Carbon Portal. The web design, data traceability and download and usage statistics as well as the enforcement of the ICOS data policy of such Thematic Centre interfaces are closely coordinated by the Carbon Portal. The Carbon Portal develops efficient search capabilities that allow users to locate and retrieve data of interest, e.g. restricted to specific variable types, geographical areas or time periods. To this end, the Carbon Portal maintains an up-to-date collection of metadata of the data provided by the Thematic Centres.

Maintaining ICOS data and metadata standards

The harmonisation of data and metadata standards, together with graphical formats and links to new products, are coordinated within the ICOS RI under the responsibility of the Carbon Portal. Concerning data formats, the Carbon Portal may offer various options to meet user needs with online/offline automatic conversion tools (for example, ASCII for time-series point measurements, NetCDF for spatial data). Relevant metadata standards (for example, ISO 19115, Dublin Core, DIF) are provided by the Carbon Portal.

Providing web services for users

The overall architecture of the Carbon Portal and the Thematic Centres' side software for publishing data and metadata is based on Web service solutions. Web services were developed for publishing metadata, searching within metadata repositories, visualising data and retrieving data. Additional services

(for example, processing services) as well as procedures and techniques (such as Web service composition) were also developed in the Cloud and in Carbon Portal environments to offer special services to public users and decision-makers, enabling them to generate their favourite information (for example, risk, alarm or emergency maps) from ICOS and/or with integration with other external data resources. Special interactive Web interfaces (for example, Web mapping interfaces) have been developed, allowing users to manage and/or process data at a basic level and create their own simple tables and graphs.

Traceability of downloaded ICOS data

The traceability and citability of ICOS data products are ensured by applying a system of unambiguous data identifiers, for example, DOIs as well as ICOS-internal dataset identification schemes. The Carbon Portal has the overall responsibility for coordinating and ensuring the implementation of (internal and external) data identifiers for all ICOS data products. The citation and referencing of DOIs and data publications offer a simple bibliometric means of tracing and measuring the data usage through its referencing in the scientific literature.

Tracking of publications based on ICOS data

ICOS data users are encouraged to submit copies of any publications that report studies using ICOS data when they are published. The Carbon Portal keeps track of this record and completes the list by conducting searches using bibliometric tools (for example, ISI, Scopus) in order to make it exhaustive. Links to publications based on ICOS data available on the internet are provided by the Carbon Portal. Any other outcome of the use of ICOS data is also documented on the Carbon Portal. Relevant information on data usage and ICOS visibility is collected, including the number of downloads, the number of visits to the portal, the number of papers and media coverage of ICOS.

User registration and traceability

In accordance with the ICOS data policy, the Carbon Portal tracks what data or information users have accessed or downloaded. This allows for the assessment of which data are most interesting to users or for establishing user profiles. Download tracking also contributes to showing the interest of users in the ICOS network to the funding agencies of ICOS' infrastructure and to improving the effectiveness and efficiency of the system. Access to ICOS data follows the ICOS data-use policy, which in turn complies with GEOSS (Global Earth Observation System of Systems) data-sharing principles.

Coordinating ICOS data descriptions and releasing publications

Processed and quality-controlled datasets offered via the Carbon Portal may be frozen on a periodic basis and subsequently published in specialized journals, for example, *Earth System Science Data*. The frozen datasets, also known as Data Releases, are also available through the Carbon Portal in parallel with the continuously updated 'live' datasets. With the Thematic Centres, the Carbon Portal coordinates the peer-reviewed publication of descriptions of the ensemble of the databases. The publication may be done regularly with each 'freezing' of the database, for example, annually. This publication ensures bibliometric recognition of the work performed by the Monitoring Station Assembly Principal Investigators and the Thematic Centres.

Coordinating, facilitating and ensuring production of elaborated products based on ICOS data

Level 3 data products (see Chapter 3) that are derived from ICOS observational data, such as greenhouse gas fluxes on a grid, have the potential to significantly increase the scientific impact of ICOS. Encouraging the production of Level 3 products and making them readily available to downstream users is a key goal of ICOS. To ensure the broad participation of diverse modelling groups and to accommodate uncertainty, the Carbon Portal takes a proactive role in initiating synthesis and upscaling efforts based on ICOS Level 1 and Level 2 data. To try to make a wide and representative range of Level 3 products available to stakeholders, the Carbon Portal coordinates external ensemble modelling activities and synthesises their results.

Display of and access to elaborated data products

Level 3 data products increase the scientific impact of ICOS, and an important task of the Carbon Portal is therefore to act as a clearinghouse that will offer access and proactive publicity to all Level 3 products that are based on ICOS observational data, including, but not limited to, flux production efforts. The flux products may be generated within ICOS (by the Carbon Portal) or by external users (modellers), both from the large scientific community within the ICOS consortium and outside of it. Comparisons between products may be developed by the Carbon Portal. Contributions are open to any product of high scientific quality, but contributions should ideally be extensively based on work published in the international peer-reviewed literature by the contribution team.

Interfaces with other data portals in and outside of Europe

Interfaces with relevant data portals were established by the Carbon Portal team. This involved, at minimum, liaising with those other initiatives for visible links between the portals. Links with external, specific thematic data centres (Atmosphere, Ecosystem and Ocean) are managed by the Thematic Centres with technical support from the Carbon Portal. Whenever possible, the interfacing can be stronger. The Carbon Portal team collaborates with these data portals to ensure mutual or unilateral discoverability and accessibility (within the respective portal search engines) that are technically feasible and respect intellectual property rights (IPRs), notably with the GEO/GEOSS-related portals. In doing so, the Carbon Portal ensures that ICOS data will remain accessible under the authentication and authorization schemes defined for ICOS data by the Carbon Portal.

IT services for the ICOS community

ICOS ERIC supports the scientific ICOS community with some useful IT tools to facilitate the cooperation.

NextCloud Fileshare: document sharing & editing in the cloud. A cloud-based service to store and share your documents (text, spreadsheets, presentations, any data file) with colleagues. The fileshare offers a cooperative document editor like Google Docs (highly compatible with MS Office), so that you can work with many persons simultaneously on manuscripts, data and presentations, with guaranteed privacy. We assign you the permissions to the right group shares when you register. Beware that processing your registration can take a few working days.

Main link: fileshare.icos-cp.eu

Further info and help: bit.ly/2Vp6oVk

Mailing lists. Email lists offer both moderated and unmoderated discussions, and possibility to archive and search for messages. Users can subscribe or unsubscribe themselves. You can join published lists through lists.icos-ri.eu. You can request to have your own mailing lists for an ICOS related activity at www.icos-cp.eu/emaillist_request.
Main link: lists.icos-ri.eu
Further info and help: bit.ly/3eGoEBt

Curation of research data products. Our curation specialists can help in finding a good place for sharing your research data, just send a mail to info@icos-cp.eu. ICOS Carbon Portal can be the right repository to long-term preserve your data. You can mint your own DOI and set the right metadata at our DOI minting interface and then we can help you in transferring the data to out trusted repository. We expect to receive the CoreTrustSeal certificate in spring 2022.
Main link: doi.icos-cp.eu

Websites. ICOS can host the website for National Networks or other facilities. Currently, four NNs use this service. Carbon Portal uses the CMS Drupal V8 system and helps to make sure that the website follows the ICOS visual guidelines.
Main contact point for these services:
info@icos-cp.eu

Jupyter notebook services and Python Data Access Library. Jupyter notebooks are the modern and interactive way to work together on scientific workflows and to improve the reproducibility of science when working with (large) datasets. Carbon Portal provides a Jupyter Hub that gives a free access to a large number of demonstration notebooks. Through the easy-to-use ICOSCP Python Library, you can access directly to all the ICOS time series and many other data and metadata at the ICOS repository.
Further info & access to ICOS Jupyter Hub:
www.icos-cp.eu/data-services/tools/jupyter-notebook
Further info on ICOS Python Data Access Library:
icos-carbon-portal.github.io/pylib

Head Office

The Head Office (HO) is the organisational hub of the entire ICOS RI. It supports and connects all the bodies of ICOS ERIC. Furthermore, the HO coordinates the operations of ICOS RI in close cooperation with the Research Infrastructure Committee (RI COM) which has representatives from other bodies of the RI. The Head Office is led by the Director General (DG).

The Head Office prepares the meetings of the overall governing body, the General Assembly (GA), and implements its decisions. The HO prepares and monitors the annual work plans and budgets, and it oversees the implementation and updates of ICOS strategy. DG and the HO have developed a broad network for international cooperation and effective communication, including videos and exhibitions during the past years and will even increase these efforts in the future.

The Head Office works together with the Central Facilities to coordinate overall activities and develop the ICOS RI. The activities and deliverables are discussed, and possible problems solved together when needed. The Head Office coordinates and supports the Monitoring Station Assemblies, stations, and

National Networks and is responsible for managing the contracts with the hosts of ICOS Central Facilities. Furthermore, the Head Office coordinates and facilitates future network development and extension in cooperation with the ICOS Central Facilities and Monitoring Station Assemblies.

The administrative areas within the Head Office include, for example: Acting as the General Secretariat for the General Assembly, Chair and Vice-Chair and providing support to the Financial Committee, the SAB, EAB and the GA delegates; Human-resource management of the ERIC; Financial management of the ERIC and planning and coordinating the ICOS RI financial management as specified in the ICOS Financial Rules, as well as supporting the procurement and managing the service providers of the ERIC.

The Head Office is also tasked with communications and outreach. Through its actions and through supporting the National Networks and Central Facilities' communications, the HO aims to increase the awareness and perceived value of ICOS and its data among key external stakeholders and to strengthen the sense of belonging among its own community. Educating the general public about importance and methods of greenhouse gas measurement is also within the scope. Actions include a unified ICOS brand: producing online and printed materials and managing communications channels as well as marketing and events.

The amount of work needed in the areas described above has varied over the years. In the beginning, community building and design needed much efforts, then construction and now operation. Consequently, the number of personnel in the HO, and the funding of the tasks have developed throughout the ICOS RI life cycle, with project funding providing the important extra resources for the development. In the future, we expect that basic funding will cover the resources needed, while potential projects will continue to fund and develop ICOS RI in the future.

Head Office tasks

- Strategic development
- Support for the operations and development of the RI
- Administrative and financial management of ICOS ERIC and the ICOS RI
- Outreach and communications
- Management of external cooperation
- Management of ICOS ERIC's participation in externally funded projects

ICOS makes a significant contribution to the European and the global climate-science community by:

- Increasing the volume of available data.
- Greatly enhancing the measurement and data quality of many measurement sites that lacked knowledge, funds or instruments to meet ICOS standards.
- Improving access to data and data uniformity throughout its network.
- Developing measurement standards and protocols.
- Providing reference samples through the CALs.
- Bringing greenhouse gas scientists across Europe together as a community, increasing collaboration and the sharing of results.

5 ICOS' IMPACTS: Better science, better knowledge, better world

More accurate greenhouse gas information enables better science, provides important background information for decision-makers and helps to avoid costly mistakes. ICOS has become the base of a scientific value-chain supporting global policy- and decision-making to combat climate change and its impact, as stated by the external evaluators in the Five-Year Evaluation Report in 2021.

The benefits of ICOS are spreading across society. Decisions are based on many standpoints, with science being only one of them, and results can be seen within very different timescales. Defining the socio-economic impact of environmental research infrastructures such as ICOS is challenging, since they observe long-term environmental phenomena requiring a long time series of data. The data provide knowledge for societal mitigation and adaptation processes that often take decades or even centuries.

The impacts of ICOS result from its interlinked strategic activities: sustainability, scientific excellence, societal impact, international cooperation, and innovation.

The ICOS Science Conference, for example, contributes to all of the impacts in this chapter. The biennial conference endorses the scientific impact by providing a platform for scientists to discuss about their discoveries and learn from each other. Technological impact is nourished at the conference's Vendor Expo, which provides opportunities for sensor and instrument manufacturers as well as hands-on users, especially scientists, to innovate together. The conference alternates special sessions and events, for example on high-level dialogues and climate communication, to interact with the decision- and policy makers as well as society.

ICOS' impacts on science

ICOS improves the quality, spatial resolution and time-series length of greenhouse gas observations in several ways. For example:

1. ICOS enables the combination of diverse datasets from various countries and across the Atmosphere, Ecosystem and Ocean domains.
2. ICOS provides financial stability for the operation of measurement stations, extending the time horizons from often project-based funding to a more long-term model.
3. ICOS sets a high level of standardisation.

ICOS started to provide data from ICOS-labelled stations in late 2017, and nowadays there are already a large number of researchers making use of ICOS services. This is also supported by the global coverage of IP addresses accessing ICOS data.

A DOI-minting process done by ICOS Carbon Portal database shows that ICOS-originated papers (Figure 8) have the potential to be widely cited

(Figure 9). The DOIs are a rather new development in data use, and thus not yet as widely used as ICOS would hope for.

From the figures, however, it is evident that the publication and citation trends of ICOS data go strongly upwards, demonstrating the increasing use of ICOS data in science. In addition, possibly because of the breadth of ICOS' coverage of oceanic, atmospheric and land-based observations, ICOS-originated publications cover a large number of journals.While this is good for visibility, it hinders the effective measurement of ICOS' impact.

The combination of ocean, atmosphere and ecosystem data and their measurement/analysis communities provides added value for the scientists. This added value lies in connecting the previously separated domains, making cross-comparisons possible and sprouting original research ideas.

ICOS' impact is also amplified by its role as the analytics and synthesis service provider for the wider scientific community. ICOS is the main European provider to the global atmospheric, ecosystem and oceanic datasets of, for instance, GLODAP, SOCAT, FLUXNET and the National Oceanic and Atmospheric Administration's (NOAA) Observation Package. These products are integrally used in (inverse) modelling by the global climate modelling community. ICOS also provides physical services through the Thematic Centres and the Central Analytical Laboratories (CAL). These are widely used,

Figure 8. ICOS-related publications, 2010–2020.

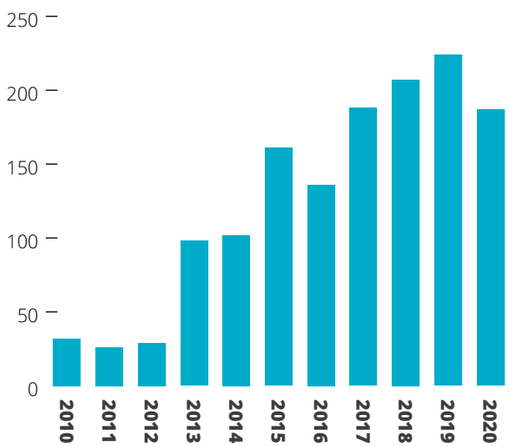
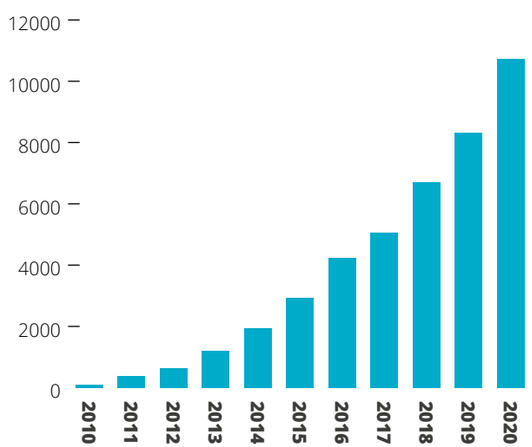


Figure 9. Citations of ICOS-related publications, 2010–2020.



and the CAL are gaining importance in the global reference-sample network, being second to only NOAA, which has performed this role for decades.

ICOS also works together with many other RIs to facilitate science. Some of the ICOS stations are co-located, while some of them provide an access via the Solutions for Sustainable Access to Atmospheric Research Facilities (ATMO-ACCESS) project. As one of the oldest ERICs, ICOS is also working in cross-RI projects such as the ENVironmental Research Infrastructures building Fair services Accessible for society, innovation and research (ENVRI-FAIR) and the Research Infrastructure Training Plus (RItrainPlus) to share its lessons learned with less experienced RIs.

ICOS' socio-economic impacts

Environmental RIs in general, and ICOS in particular, generate important knowledge on our ecological life-support systems, which provide valuable services. This is especially evident in the field of greenhouse gas management; if we do not manage to reduce the climate change sufficiently due to inadequate actions, the global warming will lead to extremely large societal costs caused by adaptation efforts, losses and damages. Compared to the values at risk, the investments and running costs needed for a global greenhouse gas monitoring and analysis network are marginal and would easily provide return due to the improved effectiveness of the science-guided mitigation strategies.

The role of ICOS at the policy level can best be described as the contribution of timely information relevant to greenhouse gas decision-making, thus supporting efforts towards the fulfilment of the Paris Agreement aimed at mitigating climate change. The role of ICOS towards the United Nations Framework Convention on Climate Change (UNFCCC) and its member countries was further strengthened in late 2019, when ICOS was accepted as the Observer to the UNFCCC. This allows ICOS to easily contribute to the scientific cycle of the UNFCCC, to the IPCC reports as well as to impact the parties in COP meetings through own events, for example.

However, greenhouse gas measurements and the related reports influence decisions only indirectly. Covering the whole range of essential climate variables requires cooperation between diverse RIs and organisations. Additionally, close collaboration is needed with the societal end-users of these observations in order to base climate policy and decisions on the best available science, as required by the Paris Agreement. As the first Global Stocktake of the Paris Agreement is approaching, actors in all levels from cities to global bodies are interested to map not only the emissions and their changes, but also how the actions to reduce emissions effect concentrations in the atmosphere and the entire carbon cycle. Data provided by ICOS is essential for this.

The UNFCCC is the global framework in which greenhouse gas emissions are monitored, and action is implemented to reduce them. The Global Climate Observing System (GCOS) defines the essential climate variables that must be systematically observed. Together with the World Meteorological Organization (WMO) and its Integrated Global Greenhouse Information System (IG3IS), ICOS provides the necessary data on the situation of greenhouse gas concentrations and fluxes in Europe. In the interviews conducted for the ICOS Impact Assessment, WMO officials mention that the measurement standards of ICOS are the best available in the world and that ICOS data are the core of global GHG inventories.

Contacts between ICOS and WMO are active at many levels. The Director of the ICOS Carbon Portal chairs the scientific advisory group for greenhouse gases of the WMO Global Atmosphere Watch Programme (GAW) and is a member of the executive steering group of the IG3IS initiated by the WMO. This allows a fertile interaction to constantly improve the ICOS data processing and the concepts used for data portals. IG3IS uses atmospheric observations and inverse modelling to provide information on the national emissions and subnational mitigation options. The system is an important monitoring tool for the Paris Agreement. It is also noteworthy that several ICOS Principal Investigators acted as lead authors in writing the IG3IS implementation plan.

ICOS is a Participating Organization in the Group on Earth Observations (GEO), a network of over 100 member countries and 120 participating organisations that aims to promote the importance of coordinated, comprehensive and sustained earth observations and information for the political decision-making process. The GEO framework allows ICOS to share experiences on best practices and measurement protocols on data acquisition, to increase the use of ICOS data and data products and to co-design the services expected from ICOS.

Several parts of the ICOS RI provide their expert contribution to the Copernicus in situ coordination project led by the European Environment Agency. ICOS is represented by the Carbon Portal, and the ATC and CRL provide their expertise, for example, in $^{14}CO_2$ observations for fossil-fuel CO_2 estimates. The ATC participates in the Copernicus Atmosphere Monitoring Service (CAMS) project of the European Union's Earth Observation Programme, which aims to consolidate and improve the preparation, transmission and quality control of near-real-time ICOS atmosphere data for the benefit of ICOS and other users.

The data in the Copernicus service will be utilised, for example, by national weather services or private companies to improve air-pollution predictions and also to develop other data products based on ICOS data, such as maps of fossil-fuel emissions.

Finally, ICOS has a unifying impact at the governmental level by means of science diplomacy. An international collaboration such as ICOS brings together not only scientists but also representatives of the research- and environment-related ministries who participate. Persons external to ICOS Member countries, who were interviewed for the Impact Assessment in 2018, mention the fact that the states from the European Union have successfully come together to make a joint observation facility and that should not be underestimated as getting people on the same page is very important and not trivial.

ICOS is increasing awareness of greenhouse gases

ICOS uses communications to increase the awareness and perceived value of ICOS and its data products among key external stakeholders, and to increase the community's engagement in ICOS. The third general goal is to increase general awareness of greenhouse gas measurements. For this, a wide pallet of tools is being used.

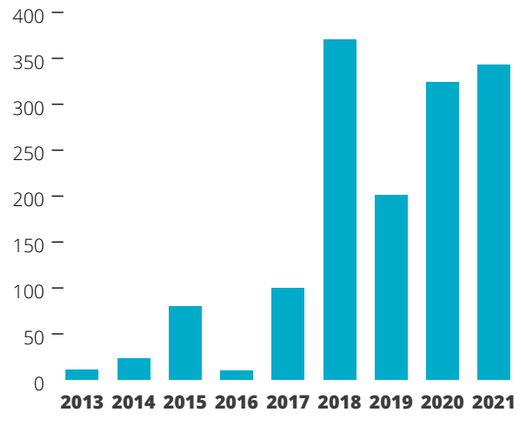
Social media is the most important external communications channel; particularly Twitter, Instagram, YouTube and LinkedIn.

The #ICOScapes social media campaign has since 2017 raised awareness on climate change and the work of scientists, through photographs taken at 12 ICOS stations. The campaign has been very successful e.g. in terms of increased visibility. Since 2018, the #ICOScapes prints have been circulating around Europe in exhibitions organised by National Networks, and have also been presented in a virtual exhibition in 2021–2022.

Since spring 2021, the Carbon Portal Webinar Series has trained users to access and visualise ICOS data effectively and to use Jupyter Notebooks and other Virtual Research Environments (VREs). The ICOS Cities Talks webinar series started in autumn 2021 to raise awareness around greenhouse gas measurements and climate change in urban landscapes. The webinars gather experts from around the globe giving their view on current topics. The webinars are open for everyone and especially students, researchers and other professionals are targeted. The webinar series is part of the ICOS Cities (PAUL – Pilot Applications in Urban Landscapes) project.

ICOS HO works actively with the media to promote ICOS-related topics, as show in Figure 10. The high annual numbers usually result from new countries joining ICOS ERIC, stations receiving ICOS label, online campaigns such as #ICOScapes and research efforts carried out within ICOS such as the Drought Initiative and the COVID-19 related studies. For example, the largest newspaper in Finland published a 10-page multimedia article highlighting the work of ICOS Finland's Focal Point Annalea Lohila in

Figure 10. The number of media articles mentioning ICOS in 2013–2021.



autumn 2021. The article linked to the ICOS Pallas station data and landing page in Carbon Portal. This led to an immediate increase in the number of visitors on the Carbon Portal and the ICOS website.

Furthermore, National Networks and Central Facilities also actively promote the importance of greenhouse gas research. They have participated in local or national science days and climate events, produced educational materials and worked together with ICOS HO to highlight their results in the media.

ICOS' impact on technology and innovation

In addition to the innovative ICOS data approach, which is an example of the way forward in using FAIR principles in environmental research data, ICOS also drives technical innovation.

Scientists at ICOS continuously apply novel approaches by creating new instrumentation set-ups and measuring greenhouse gases in places where they have not been previously measured. ICOS scientists and the rest of the ICOS community comprise a crucial and large knowledge network, which collaborates with companies to improve the instruments in cooperation with manufacturers.

The industrial partners have indicated in the Impact Assessment in 2018 that ICOS' high standards drive them to increase their product quality, induced by the testing and calibration conducted at ICOS sites as well as different meetings and events, for example. In 2018, prior to the data release, the industrial partners expected that the influence of ICOS in their industrial market will increase once ICOS starts to publish data measured with their products.

Examples of cooperation between the industry and ICOS can be found in all domains. The ATC metrology lab has built collaborations with industrial companies to test emerging technologies. Innovative ICOS ATC software is used by ICOS Principal Investigators for quality control and for station network management systems. The ETC and Carbon Portal cooperated with private companies in the development of a specific logger for the automatic data-submission process. The OTC has partnered with Saidrone, a private company to validate the ICOS ocean data from fixed ocean stations using a wind-powered, fully autonomous ocean drone. OTC is also engaging instrument suppliers to an inter-comparison campaign to reach a high level of standardisation. Ongoing dialogue and competition between companies as well as manufacturers drives for production of even more accurate and improved sensors and measurement instruments. In this regard, ICOS' technological readiness and impact also rely on the research and innovation carried out in companies which produce the equipment, such as Picarro, LI-COR, Pro-Oceanus Systems and Vaisala.

6 HOW TO BECOME AN ICOS ERIC MEMBER OR OBSERVER

A country can be either a Member or an Observer of ICOS ERIC. Both pay an annual contribution and have different rights and obligations. The main difference is that Members can attend and vote at the General Assembly, while Observers can attend without a vote.

Member rights and obligations are listed in the ICOS ERIC statutes and are the same for all Members, whereas the rights and obligations of Observers are negotiated individually between the Observer and ICOS ERIC.

ICOS ERIC Members currently include Belgium, the Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, the Netherlands, Norway, Spain, Sweden and the United Kingdom. Switzerland has Observer status in ICOS ERIC.

Requirements for becoming a Member or an Observer

Member States of the European Union, associated countries, countries other than associated countries and intergovernmental organisations may become Members or Observers. An additional requirement for membership is that the Member must contribute to the operation of ICOS ERIC and/or host an ICOS Central Facility and/or a National Network. Figure 11 summarises the process of becoming a Member or Observer.

Member and Observer applications

When a country or intergovernmental organisation is interested in joining ICOS ERIC as a Member or as an Observer, it should contact the Head Office of ICOS ERIC to further discuss its plans. ICOS will help the applicant by providing information and a contact person to assist with the preparation and application phases.

The applicant should as soon as possible, and at least six months before submitting its application, describe how it wishes to participate and how many and what kind of stations it is willing to bring to ICOS RI.

The applicant should name its national Focal Point, who will act as a contact person for ICOS and ensure the organisation of its national consortium.

The application should also include information on the representing entities and the name(s) of the applicant's representative(s) to the General Assembly. A Member is entitled to appoint up to three representatives, whereas an Observer is entitled to appoint one representative.

The applicant should also state which organisations will be its representing entities in accordance with the ICOS ERIC statutes, Article 3(5).

The admission of a new Member or an Observer requires the approval of the ICOS ERIC's

General Assembly. The applicant will be invited to join the General Assembly meeting. When approved, the Membership/Observership always starts at the beginning of the next financial year.

The application to become a **Member** should describe how the applicant will be involved in the ICOS RI and how it will participate in the realisation of the tasks and activities of ICOS ERIC according to the ICOS ERIC statutes, Article 2. It is especially important to list how many and what kind of stations the applicant is ready to bring to the ICOS RI. The application should also include a statement that the applicant fulfils the Membership obligations stated in the ICOS ERIC statutes, Article 6(2).

The application to become an **Observer** should describe how the applicant will be involved in the ICOS RI and whether it will participate in the realisation of the tasks and activities of ICOS ERIC according to the ICOS ERIC statutes, Article 2. It is especially important, if such is intended, to list how many and what kind of stations the applicant is ready to bring to the ICOS RI.

Figure 11. Steps towards ICOS membership.

Preparing phase

- The applicant contacts the ICOS Head Office.
- The Head Office provides the applicant with more information and contacts.
- Discussions between the applicant and ICOS: How you wish to participate and which stations to include.
- ICOS will calculate the membership costs and plan the integration of stations.
- The applicant is invited to participate in ICOS General Assembly meetings as a guest.

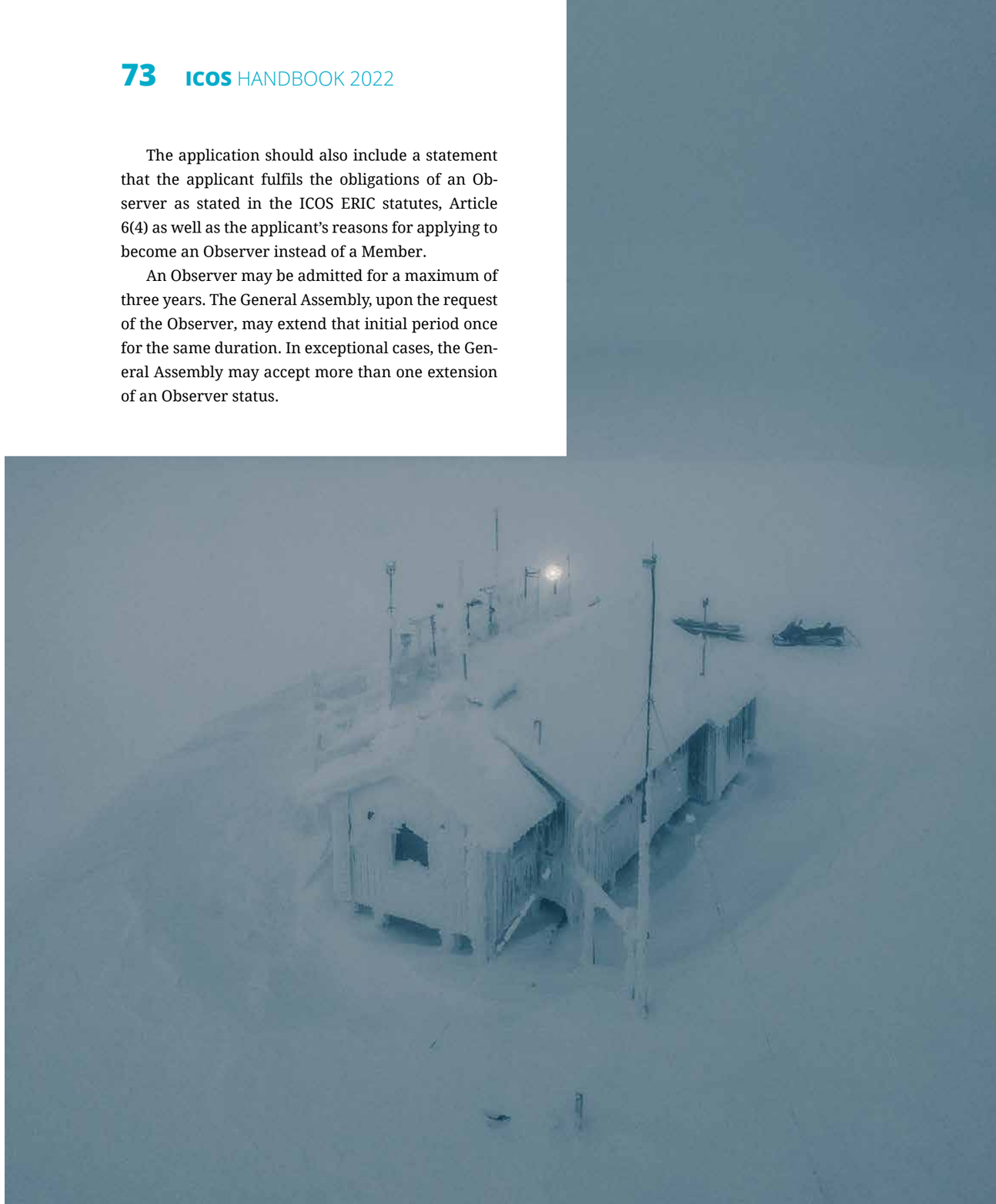
Application phase

- The country writes an application.
- The ICOS General Assembly approves the new Member country.
- The membership starts from the beginning of the next financial year.

Send to:
Director General / ICOS ERIC
Erik Palménin aukio 1
00560 Helsinki, Finland

The application should also include a statement that the applicant fulfils the obligations of an Observer as stated in the ICOS ERIC statutes, Article 6(4) as well as the applicant's reasons for applying to become an Observer instead of a Member.

An Observer may be admitted for a maximum of three years. The General Assembly, upon the request of the Observer, may extend that initial period once for the same duration. In exceptional cases, the General Assembly may accept more than one extension of an Observer status.



7 ICOS COUNTRIES: Cooperation for better data

The ICOS RI network consists of 149 (in 2022) measurement stations located in fourteen countries in Europe. ICOS member countries include Belgium, the Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, the Netherlands, Norway, Spain, Sweden and the United Kingdom. Switzerland has the observer status in ICOS ERIC. Together, these countries form a station network reaching all the way from the Arctic to the equator. All the stations produce high-quality data on greenhouse gases that are accessible by anyone through the ICOS Carbon Portal. A comprehensive standardised network guarantees that the data is precise and reliable, which is crucial both for high-quality research and for effectively mitigating climate change.

The number of stations varies between member countries from over thirty stations to fewer than five. The oldest operating stations have been collecting data for decades. However, all these stations were re-equipped to meet the high ICOS standards and some stations have been built from scratch for ICOS RI. Stations operate in three different domains: Atmosphere, Ecosystem and Ocean.

The Atmosphere, Ecosystem and Ocean networks include two classes of stations: Class 1 stations are equipped with complete equipment for measuring a full set of predetermined ICOS variables, and Class 2 stations are equipped for measuring a predefined subset of the ICOS variables. Importantly, the standardisation and quality of the data are at same level in both station categories. In addition, the ICOS Ecosystem network is supplemented by a set of Associated stations in which the requirements, in terms of the variables examined and the standards followed, are different from the Class 1 and Class 2 stations.

Each National Network is managed and coordinated by a number of national research institutes. The number of partner organisations and the funding structures vary between member countries.

This chapter describes the ICOS member and observer countries; that is, the National Networks, their role in the European network, the stations and how the operation is funded. The contact information for each National Network is provided, together with a comprehensive list of partners and funders.

The station network maps in the following pages are illustrations and rather simple snapshots of the network in 2022. For up-to-date and more detailed maps with adjustable layers, please visit www.icos-ri.eu.

ICOS Belgium

ICOS BELGIUM FOCAL POINT
Ivan Janssens
Professor
Plants and Ecosystems, PLECO
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+32 3 265 22 55
www.icos-belgium.be

Simon Stevin: An Ocean station of ICOS Belgium

The role of ICOS Belgium

Belgium hosts 11 stations in total and is involved in all three observation networks. The University of Antwerp is hosting the Ecosystem Thematic Centre (ETC) together with INRAE (France) and CMCC (Italy). Despite Belgium's diverse landscape and high human density, the ICOS-BE network covers well the typical land-uses and economically important North Sea. The Belgian network also comprises two overseas stations located in the Democratic Republic of Congo and Réunion Island.

The forest sites of Brasschaat and Vielsam are two of the longest-running and most complete flux stations in the world. Lochristi, located in 11 ha of fast-growing poplars, is the only bioenergy plantation station in ICOS. Thanks to its location near the Thornton wind farm, the Thornton buoy is one of the few fixed Ocean stations in the world that can rely on a Wi-Fi and mobile connection for data transmission. Maasmechelen was constructed in Belgium's only national park and is the first European heathland site where greenhouse gases are monitored. The station is closely linked to the Ecotron of Hasselt University (AnaEE), providing the necessary data to control the Ecotron's chamber environment. In a similar way, the Lonzée station located in a cropland is closely linked to the AneEE Ecotron of the University of Liège. The Belgian network further contributes to carbon observations in the Southern Hemisphere through the Yangambi station. This new state-of-the-art tower is the first one to record flux measurements in Central Africa.

The Belgian stations have strong links with other international research infrastructures. Ship of Opportunity Simon Stevin is also used in LifeWatch, Brasschaat and Maasmechelen are proposed as eLTER master sites, and Vielsalm and the Atmosphere station Maido observatory are proposed as co-located ICOS-ACTRIS supersites. The Observatoire de l'Atmosphère du Maïdo at Réunion Island is also contributing to the global Total Carbon Column Observing Network (TCCON).

The ICOS Belgium Infrastructure

The current ICOS Belgium network (Figures 12a, b) consists of 11 observation stations (Table 12) operated by nine different research institutes. The University of Antwerp acts as the national Focal Point, representing and coordinating the Belgian network. The University of Antwerp is also co-hosting the Ecosystem Thematic Centre, and is particularly responsible for the collection and processing of ancillary data, one of the three pillars of the ETC.

The Ecosystem network consists of two agricultural sites (Dorinne and Lonzée), two forest sites (Brasschaat and Vielsalm), one heathland site (Maasmechelen) and one poplar plantation site (Lochristi). A seventh Ecosystem station (Yangambi) is located in the Congo Basin, operated by Ghent University since 2021. Located in the UNESCO Man and Biosphere reserve in Yangambi, the station will contribute to the understanding of the global carbon cycle in undersampled and critical zones.

The Ocean network consists of the RV Belgica, a multidisciplinary oceanographic research and monitoring ship with a main focus on the North Sea environment, the RV Simon Stevin, a Ship of Opportunity deployed for coastal oceanographic research in the Southern Bight of the North Sea and the eastern part of the English Channel, and the Thornton buoy, anchored at the artificial reefs in the C-power wind farm, in the Belgian part of the North Sea.

The Atmosphere station at Ile de La Réunion is a Belgian-French collaboration (between BIRA and the French partners of LSCE and the Université de La Réunion) performing background measurements of greenhouse gases in the Indian Ocean. The Observatoire de l'Atmosphère du Maïdo consists of two observational stations: one close to sea level and one at about 2,100 m above sea level.

The ICOS Belgium Funding Structure

The current ICOS Belgium Consortium involves four Walloon, three Flemish and two Federal institutes. Each institute is funded by its respective government, while the Federal government represented by the Belgian Science Policy Office (BELSPO) carries the cost of the membership fees.

Until 2018, no structural funding existed for the involvement of the Flemish partners in ICOS, but a yearly subsidy was provided since 2012. Since 2018, the Research Foundation – Flanders (FWO) has launched a call every two years for structural funding for international research infrastructures. The Flemish partners have successfully secured a four year (2021–2025) funding in the 2020 FWO call.

The Walloon partners received funding in 2013 from the Service Public de Wallonie to finance three Ecosystem stations. The project, called ICOS Wallonia-Brussels, lasted eight years. By a decision of the Walloon Minister of Economy, Research and Innovation and Agriculture in October 2020, the Walloon partners of the ICOS Belgium Consortium (ICOS-WB) received funding for five years for Phase 2 of the ICOS-WB infrastructure project, which started in July 2021.

BIRA has received financial support from BELSPO through the ministerial decree for ICOS for a period of 5 years since December 2014 for running the Observatoire de l'Atmosphère du Maïdo at Réunion Island. The RV Belgica, operated by RBINS-OD Nature, is funded by BELSPO via yearly renewed grants. The federal partners received an extension of

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Figure 12a

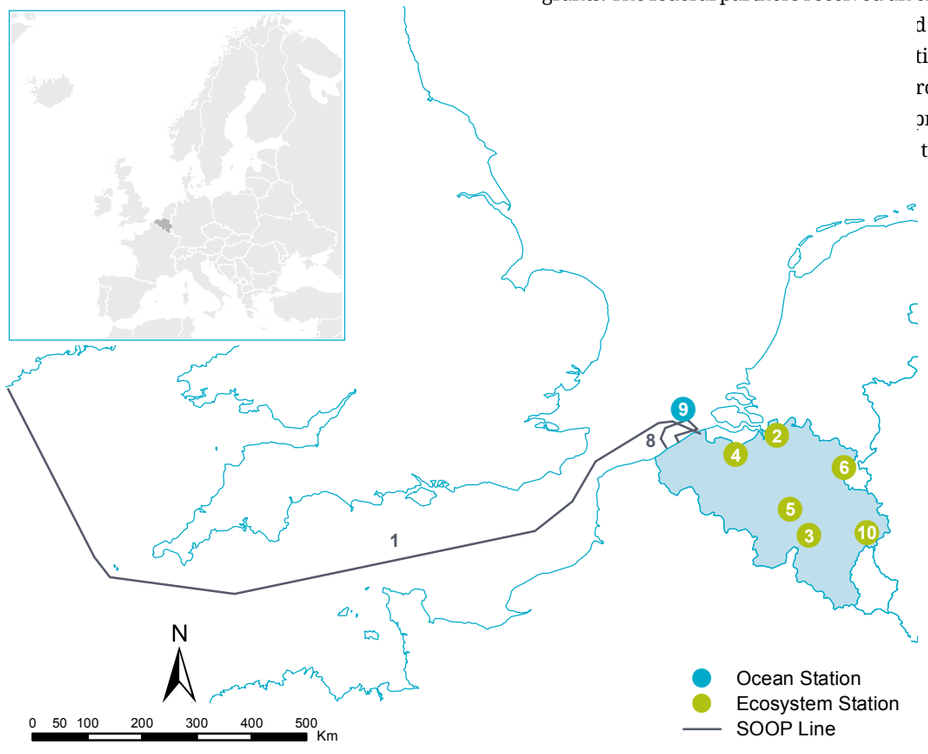

Figure 12: The ICOS Belgium station network. Figure 12a primarily covers Ecosystem and Ocean stations around mainland Belgium, while Figure 12b shows the remote Atmosphere station that is located at Réunion Island in the Indian Ocean and the Yangambi Ecosystem station located in the Congo basin. The numbers in the maps correspond to the numbers in Table 12.

Figure 12b

ICOS BELGIUM PARTNERS AND FUNDERS

Belgian Science Policy Office (BELSPO)
www.belspo.be/belspo

Department of Economy, Science and Innovation (EWI), Flemish Government
www.ewi-vlaanderen.be

Flanders Marine Institute (VLIZ)
www.vliz.be/en

Institut Scientifique de Service Public (ISSeP)
www.issep.be

Research Foundation – Flanders (FWO)
www.fwo.be/en

Royal Belgian Institute for Space Aeronomy (BIRA-IASB)
www.aeronomie.be/en

Royal Belgian Institute of Natural Sciences (RBINS)
www.naturalsciences.be

Service Public de Wallonie (SPW)
spw.wallonie.be

The Research Institute for Nature and Forest (INBO)
www.inbo.be/en

University of Antwerp (UAntwerpen)
www.uantwerpen.be/en

Université catholique de Louvain (UCLouvain)
uclouvain.be

University of Liège (ULiège)
www.uliege.be

Walloon Agricultural Research Centre (CRA-W)
www.cra.wallonie.be/en

Ghent University (UGent)
www.ugent.be

Table 12. ICOS Stations in Belgium

MAP NUMBER	STATION NAME	STATION ABBREVIATION	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
1	Belgica	BE-SOOP- Belgica	Ocean	Ship of Opportunity in the North Sea	Class 1	Royal Belgian Institute of Natural Sciences
2	Brasschaat	BE-Bra	Ecosystem	Coniferous forest	Class 1	University of Antwerp
3	Dorinne	BE-Dor	Ecosystem	Grassland	Class 2	University of Liege
4	Lochristi	BE-Lcr	Ecosystem	Short rotation coppice	Associated	University of Antwerp
5	Lonzée	BE-Lon	Ecosystem	Cropland	Class 2	University of Liege
6	Maasmechelen	BE-Maa	Ecosystem	Heathland	Class 1	University of Antwerp
7	Observatoire de l'Atmosphère du Maïdo	RUN	Atmos-phere	Mountain	Class 2	Royal Belgian Institute for Space Aeronomy
8	Simon Stevin	BE-SOOP-Simon-Stevin	Ocean	Ship of Opportunity in the North Sea	Class 1	Flanders Marine Institute
9	Thornton Buoy	BE-FOS-Thornton Buoy	Ocean	Buoy in the North Sea	Class 1	Flanders Marine Institute
10	Vielsalm	BE-Vie	Ecosystem	Mixed forest	Class 2	UCLouvain
11	Yangambi	CD-Ygb	Ecosystem	Tropical forest	Associated	Ghent University

ICOS Czech Republic

ICOS CZECH REPUBLIC FOCAL POINT

Jiří Kolman

Scientific Secretary of CzechGlobe

Czech Republic

contact-cz@list.icos-ri.eu

+420 511 192 299

www.icos-infrastructure.cz/english

Lanžhot: an Ecosystem station of ICOS Czech Republic

The role of ICOS Czech Republic

The main goal of the ICOS Czech Republic, which operates within the national research CzeCOS (Czech Carbon Observation System) infrastructure, conducts long-term research on the greenhouse gases and carbon cycles in the atmosphere and the main Czech ecosystem types. Combining measurements of the atmosphere and ecosystems, the infrastructure enables the effects of land use, climate variability and changes in the territory of the Czech Republic to be determined.

Apart from ICOS infrastructure itself, CzeCOS operates supportive complementary infrastructure, such as an aircraft laboratory providing remote sensing instruments and ecosystem experimental sites that are used in conjunction with ICOS infrastructure (e.g. multifactorial experiments in ecosystems and remote sensing research methods).

Thanks to its experience of multi-source funding, especially using EU structural funds, ICOS Czech Republic's CzechGlobe institution can serve as a model institution for ICOS candidate countries that are constructing ICOS infrastructure.

The ICOS Czech Republic infrastructure

ICOS Czech Republic is hosted and operated by a single institution: CzechGlobe – Global Change Research Institute of the Czech Academy of Sciences. The Czech ICOS stations are included in the national CzeCOS project. The Czech ICOS comprises one Atmosphere station and three Ecosystem stations (Figure 13; Table 13), and represents different ecosystem types: floodplain forest, evergreen needle leaf forest and a wetland to represent a mosaic of ecosystem types in the Czech Republic.

The Atmosphere station Křešín u Pacova is situated in the middle of the Czech Republic. It has been in operation since 2013 and it serves as a national monitoring point for both the occurrence and remote transmission of greenhouse gases, selected pollutants and basic meteorological characteristics. The station consists of a 250-metre-high meteorological research mast, at the various height levels of which atmospheric concentrations of greenhouse gases (CO_2, CH_4, CO, N_2O, SF_6), pollutants (tropospheric ozone, gaseous mercury and aerosols) as well as basic meteorological characteristics (air temperature, pressure and humidity, wind speed and direction) and the height of the atmosphere boundary layer are monitored.

The ICOS Czech Republic funding structure

The ICOS Czech Republic is part of the Czech national research infrastructure road map, which is managed by the Ministry of Education, Youth and Sports of the Czech Republic. It also provides the main funding for the operational costs of the ICOS Czech Republic infrastructure. The construction of the research infrastructure was made possible by EU structural funding for the Czech Republic in 2011–2014.

ICOS CZECH REPUBLIC PARTNERS AND FUNDERS

Global Change Research Institute of the Czech Academy of Sciences
www.czechglobe.cz/en

Ministry of Education, Youth and Sports
www.msmt.cz

Figure 13: The ICOS Czech Republic station network. The numbers in the map correspond to the numbers in Table 13.

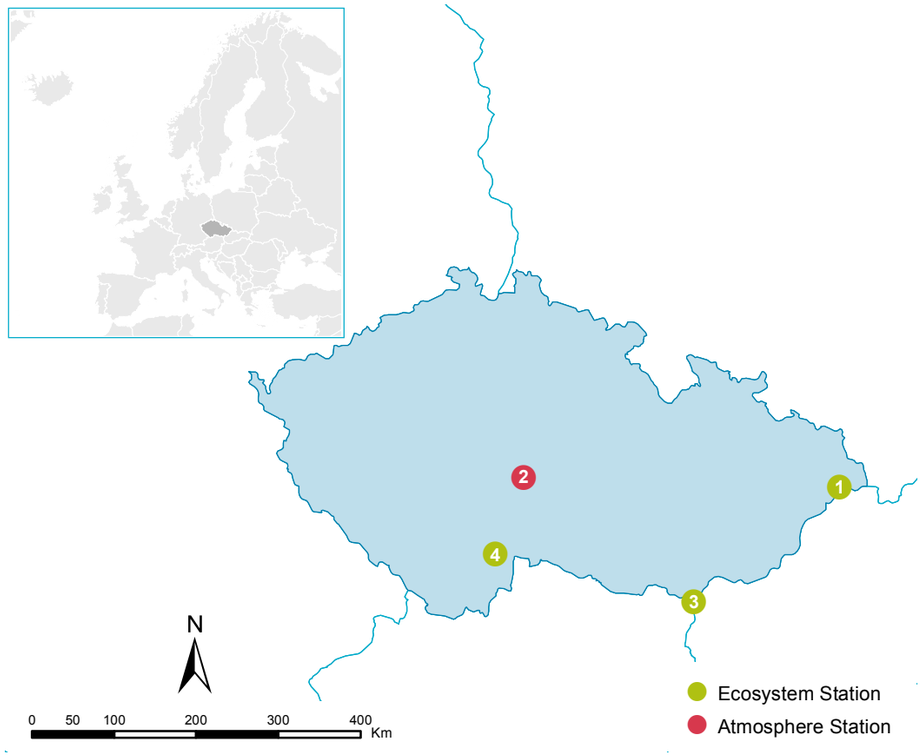

Table 13. ICOS Stations in the Czech Republic

MAP NUMBER	STATION NAME	STATION ABBREVIATION	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
1	Bílý Kříž forest	CZ-BK1	Ecosystem	Forest	Class 2	CzechGlobe
2	Křešín u Pacova	KRE	Atmosphere	Tall tower	Class 1	CzechGlobe
3	Lanžhot	CZ-Lnz	Ecosystem	Forest	Class 1	CzechGlobe
4	Třeboň	CZ-wet	Ecosystem	Wetland	Associated	CzechGlobe

ICOS Denmark

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Zackenberg Fen: an Ecosystem station of ICOS Denmark

The role of ICOS Denmark

The role of ICOS Denmark is to contribute to the ICOS RI with stations in the characteristic ecosystems of Denmark and Greenland. In addition, ICOS Denmark runs an Atmosphere station at the north-eastern tip of Greenland. The Greenlandic stations make an important arctic contribution to ICOS RI. If funding can be obtained, ICOS Denmark would like to include an Atmosphere station on the Danish west coast and contribute to the Ocean network, especially in the arctic seas.

The Ecosystem stations of the Danish network all had multi-year data records before entering the ICOS RI. Furthermore, the universities running the stations all have long experience of measuring the concentration and fluxes of greenhouse gases.

The ICOS Denmark Infrastructure

The ICOS National Network of Denmark (ICOS-DK) is a consortium of four universities: the University of Aarhus (AU), the University of Copenhagen (KU), Roskilde University (RUC), and the Technical University of Denmark (DTU). The stations are run by the three universities (AU, DTU and KU), and the user and stakeholder interaction is taken care of by RUC. DTU acts as the national Focal Point, representing and coordinating the Danish network of ICOS partners.

ICOS Denmark contributes to two ICOS observation domains: Atmosphere and Ecosystem. The ICOS Denmark network consists of ten stations (Figures 14a, b; Table 14), of which one is an Atmosphere station and nine are Ecosystem stations. The network includes stations officially labelled by ICOS according to the three classes: Class 1, Class 2 and Associated. Four of the stations are in typical ecosystems in Greenland, and one is an Atmosphere station in Greenland at a location that frequently encounters air masses from Europe and Siberia.

The stations on the Danish mainland cover typical ecosystems such as farmland, forests (including short rotation coppice) and wetland. Each station performs a set of measurements according to common specifications and under the control of the Thematic Centre concerned. This ensures the standardisation of measurements, their interoperability and the relevance of the ICOS network as a whole.

The ICOS Denmark funding structure

The financing of the operation depends on a five-year grant from the Danish Agency for Science and Higher Education and matching co-financing from the universities. Additional funding for the logistics of the stations in Greenland is obtained from the Danish Ministry of Energy, Utilities and Climate and from private foundations.

ICOS DENMARK PARTNERS AND FUNDERS

Aarhus University
www.international.au.dk

Danish Ministry of Climate, Energy and Utilities
en.kefm.dk

Technical University of Denmark
www.dtu.dk/english

University of Copenhagen
www.ku.dk/english

Figure 14: The ICOS Denmark station network. Figure 14a shows Ecosystem stations located in mainland Denmark, while Figure 14b depicts both Atmosphere and Ecosystem stations situated in Greenland. The numbers in the maps correspond to the numbers in Table 14.

Figure 14a

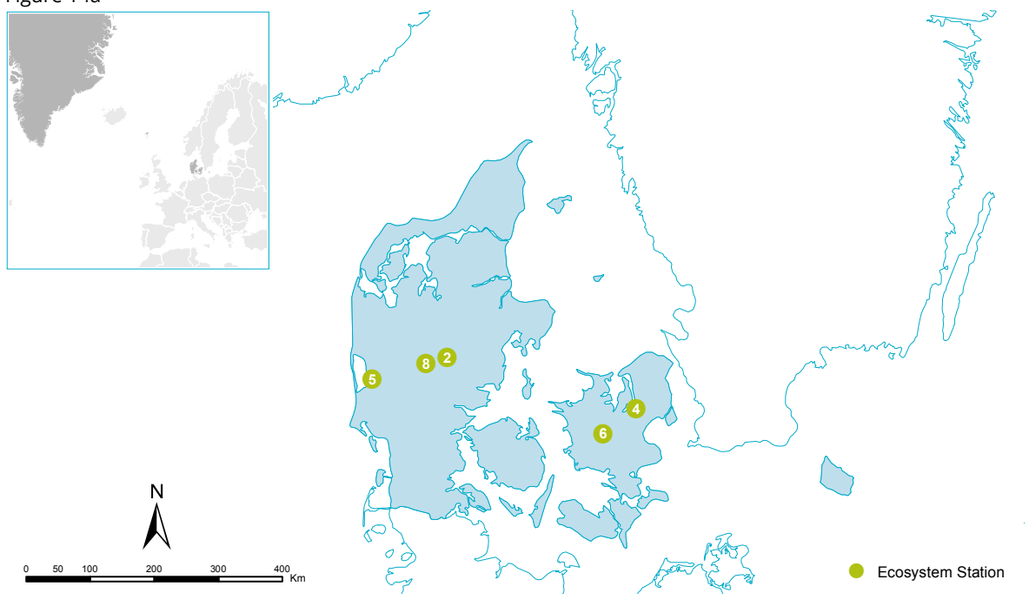

Figure 14b

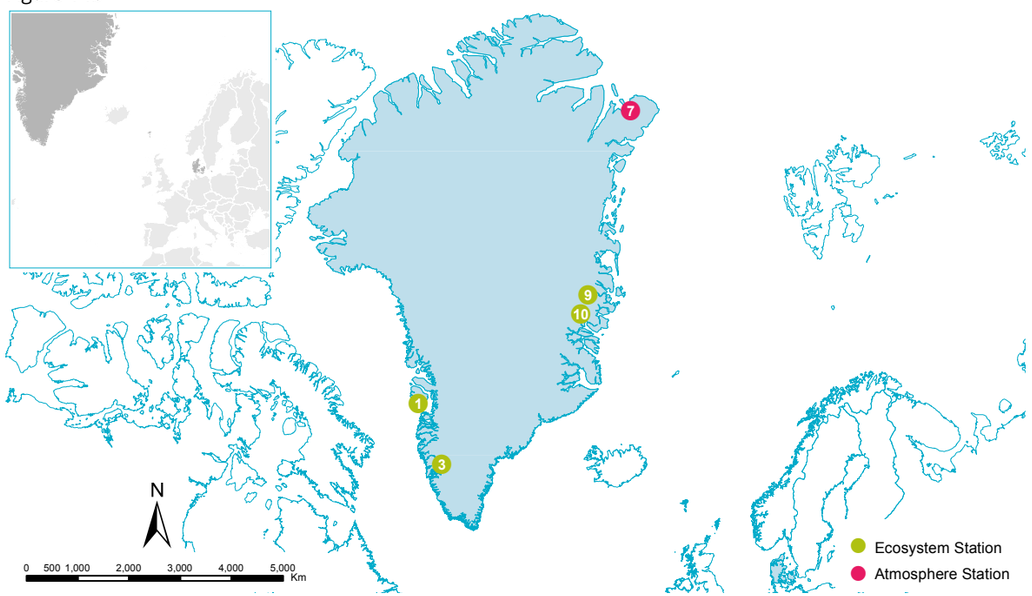

Table 14. ICOS Stations in Denmark

MAP NUMBER	STATION NAME	STATION ABBREVIATION	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
1	Disko*	GL-Dsk	Ecosystem	Heathland	Associated	University of Copenhagen
2	Gludsted Plantage	DK-Gds	Ecosystem	Forest	Associated	University of Copenhagen
3	Nuuk Fen*	GL-NuF	Ecosystem	Mire	Associated	University of Copenhagen
4	Risoe	DK-RCW	Ecosystem	Forest	Associated	Technical University of Denmark
5	Skjern	DK-Skj	Ecosystem	Wetland	Associated	University of Copenhagen
6	Soroe	DK-Sor	Ecosystem	Deciduous forest	Class 1	Technical University of Denmark
7	Station Nord*	SNO	Atmosphere	High arctic, dry and cold	Class 2	Aarhus University
8	Voulundgaard	DK-Vng	Ecosystem	Conventional agriculture	Class 1	University of Copenhagen
9	Zackenberg Fen*	GL-ZaF	Ecosystem	Wetland	Class 2	Aarhus University
10	Zackenberg Gras*	GL-ZaH	Ecosystem	Grassland	Associated	Aarhus University

*The station is located in Greenland.

ICOS Finland

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Pallas Sammaltunturi: an Atmosphere station of ICOS Finland

The role of ICOS Finland

ICOS Finland stations provide ICOS RI with useful representation of boreal and subarctic Eurasian environments in a transition zone from a marine to a continental climate. Five of the 13 stations are located above the Arctic Circle. ICOS Finland has been established by well-known partners: the University of Helsinki (UHEL), the Finnish Meteorological Institute (FMI), and the University of Eastern Finland (UEF). Research teams from these organisations have leading and active roles in many subfields in atmospheric and Earth systems research.

The Finnish partnership provides ICOS with several advantages in terms of expertise and geographical coverage. ICOS Finland studies the sinks and sources of greenhouse gases in typical boreal and subarctic ecosystems, focusing on coniferous forests and peatlands but also including the unique sites of a lake and an urban environment.

ICOS Finland provides the longest-running eddy covariance CH_4 and CO_2 flux records from Siikaneva peatland and Kuivajärvi lake stations, respectively. Hyytiälä SMEAR II station, in turn, is the flagship site of the Stations for Measuring Earth Surface–Atmosphere Relations (SMEAR) network, providing versatile information for several fields of science.

The ICOS Finland infrastructure

The ICOS Finland network consists of thirteen stations (Figure 15; Table 15), of which four are Atmosphere stations, four Ecosystem stations, and five Associated Ecosystem stations.

Seven of the ICOS Finland stations also belong to the SMEAR network. Four stations operated by FMI are part of the Pallas-Sodankylä Atmosphere-Ecosystem supersite, one of these (Pallas) belonging to the Global Atmosphere Watch (GAW) of the WMO. The GHG data from Pallas has been distributed via GAW World Data Centre for decades to atmospheric scientists who use it in global climate studies.

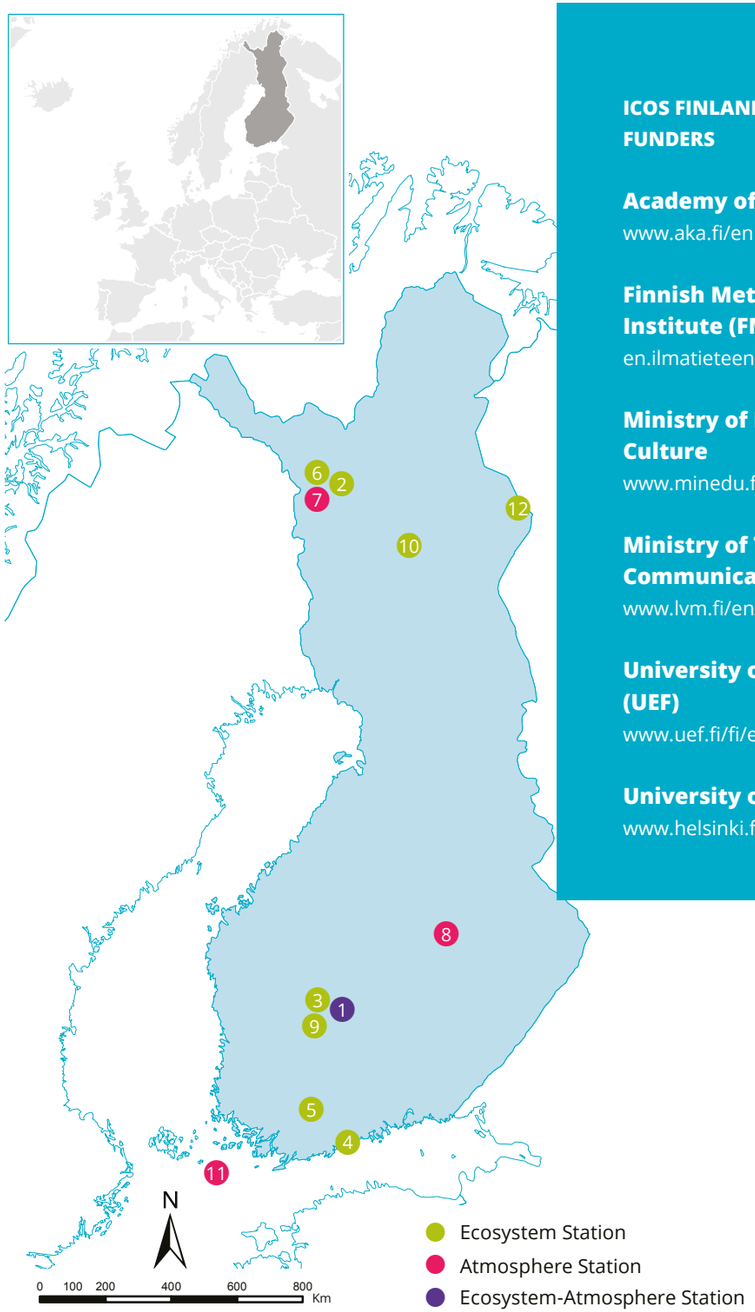
ICOS Finland provides effective access to harmonised, coherent and precise data on atmospheric CO_2 and CH_4 concentrations and exchange rates (fluxes) over forest, peatland, lake and urban surfaces. The CO_2 and CH_4 flux data are among the longest-running and most utilised in the biogeochemistry research community.

In addition to these, data on sensible heat flux and latent heat flux (evapotranspiration), as well as those on various meteorological and ecophysiological (vegetation and soil) variables are available, together with essential metadata. Hyytiälä, Utö and Puijo Atmosphere stations are complements to the earlier, quite sparse, ATM station network, which had only Pallas ATM station in Finland, and the interest in them is high.

The ICOS Finland funding structure

In 2010–2019, ICOS Finland partners UHEL and UEF have received funding from the Ministry of Education and Culture (through the Academy of Finland), while FMI has received funding from the Ministry of Transport and Communication. The share of funding obtained from the two ministries has been 50%-50%. In 2020 UHEL and UEF did not receive funding from the Academy of Finland but have maintained the stations with the funding from the founder organisations, while the funding for FMI has remained unchanged.

In early 2022, UHEL and UEF received ICOS funding for the period 2022–2025 from the research infrastructure funding instrument of Academy of Finland. Also two new partner organisations, University of Oulu and Natural Resources Institute Finland, were funded and will join ICOS Finland in the near future. The geographical and ecosystem-type representativity will be strengthened along this change.



ICOS FINLAND PARTNERS AND FUNDERS

Academy of Finland
www.aka.fi/en

Finnish Meteorological Institute (FMI)
en.ilmatieteenlaitos.fi

Ministry of Education and Culture
www.minedu.fi/en/frontpage

Ministry of Transportation and Communications
www.lvm.fi/en/home

University of Eastern Finland (UEF)
www.uef.fi/fi/etusivu

University of Helsinki (UHEL)
www.helsinki.fi/en

Figure 15: The ICOS Finland station network. The numbers in the map correspond to the numbers in Table 15.

Table 15. ICOS Stations in Finland

MAP NUMBER	STATION NAME	STATION ABBREVIATION	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
1	Hyytiälä/SMEAR II	SMR	Atmos-phere	Tall tower/southern boreal pine forest	Class 1	University of Helsinki
1	Hyytiälä/SMEAR II	FI-Hyy	Ecosystem	Southern boreal pine forest	Class 1	University of Helsinki
2	Kenttärova	FI-Ken	Ecosystem	Northern boreal spruce forest	Associated	Finnish Meteoro-logical Institute
3	Kuivajärvi/SMEAR II	FI-Kvr	Ecosystem	Boreal lake	Associated	University of Helsinki
4	Kumpula/SMEAR III	FI-Kmp	Ecosystem	Urban environment	Associated	University of Helsinki
5	Lettosuo	FI-Let	Ecosystem	Forestry-drained peatland	Associated	Finnish Meteoro-logical Institute
6	Lompolojänkkä	FI-Lom	Ecosystem	Northern boreal fen	Class 2	Finnish Meteoro-logical Institute
7	Pallas	PAL	Atmos-phere	Subarctic hill	Class 1	Finnish Meteoro-logical Institute
8	Puijo/SMEAR IV	PUI	Atmos-phere	Tall tower/urban environment	Class 2	Finnish Meteoro-logical Institute and University of Eastern Finland
9	Siikaneva/SMEAR II	FI-Sii	Ecosystem	Southern boreal fen	Class 2	University of Helsinki and Uni-versity of Eastern Finland
10	Sodankylä	FI-Sod	Ecosystem	Northern boreal pine forest	Class 1	Finnish Meteoro-logical Institute
11	Utö – Baltic sea	UTO	Atmos-phere	Non-forested island in Baltic sea	Class 2	Finnish Meteoro-logical Institute
12	Värriö/SMEAR I	FI-Var	Ecosystem	Subarctic pine forest	Associated	University of Helsinki

ICOS France

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Grignon: An Ecosystem station of ICOS France

The role of ICOS France

Within ICOS RI, the French network aims to provide the data flow required for quantifying and understanding the exchange of greenhouse gases between the continental surface, atmosphere and superficial ocean waters. The country network of stations covers the main land use types (crops, grasslands, temperate and tropical forests, and peatlands) and spans over temperate, alpine, Mediterranean and tropical climates.

The ICOS France network includes a range of management practices from annual crops to grazed or mowed meadows, fast growing pine forest plantations to managed broadleaved forests, peatland and unmanaged pristine forests. Innovative measurement methods and techniques are developed and tested at ICOS French stations; for example, the total carbon column with Fourier transform spectrometers, atmospheric profiles of greenhouse gases by AirCore, N_2O, CH_4, NHy, NOx and ozone flux measurements, and ultra-light spectrometers on drones. The Ocean network includes a merchant ship, sailing from France to Brazil, crossing different ocean biogeochemical provinces and measuring the surface fugacity of CO_2 during the journey by infrared detection.

ICOS France manages the Atmosphere Thematic Centre (ATC) located at Saclay and a part of the Ecosystem Thematic Centre (ETC) at the French National Research Institute for Agriculture, Food, and Environment (INRAE).

ICOS France infrastructure

The French ICOS consortium includes the main national research partners concerned with the carbon and greenhouse gas cycles: the National Radioactive Waste Management Agency (ANDRA), the Alternative Energies and Atomic Energy Commission (CEA), the National Centre for Scientific Research (CNRS-INEE and INSU), the French National Research Institute for Agriculture, Food, and Environment (INRAE), the University of Versailles-Saint-Quentin-en-Yvelines (UVSQ), among others. The partners are involved in international research programmes on climatology, environment, ecology, oceanography, agronomy, and forestry, among them the IPCC, the Global Carbon Project, Fluxnet.

The ICOS France network encompasses three ICOS observation domains: Atmosphere, Ecosystem and Ocean. The French network consists of 23 stations (Figures 16 a, b, c, d.) of which five are Atmosphere stations, 17 are Ecosystem stations and one is an Ocean station (SOOP). Each station performs a set of measurements according to common specifications and under the control of the corresponding Thematic Centre. Class 1 and 2 stations form the main framework of the infrastructure and are committed for a period of 20 years.

In addition to the stations, France hosts the Atmosphere Thematic Centre at Saclay (CEA-CNRS-UVSQ) and co-shares the Ecosystem Thematic Centre (INRAE) in coordination with Italy (CMCC) and the University of Antwerp. Furthermore, France is in charge of the ICOS plant and soil analysis laboratories in Bordeaux and Arras, respectively, and the European Soil Conservatory in Orléans.

The ICOS France funding structure

The ICOS France network is mainly funded by voluntary contributions from the host institutions: the National Radioactive Waste Management Agency, the Alternative Energies and Atomic Energy Commission, the National Centre for Scientific Research, the National Research Institute for Agriculture, Food, and Environment and the University of Versailles-Saint-Quentin-en-Yvelines.

Altogether, the host institutions employ 90 permanent staff devoted to the station network, and Thematic Centres employ a manpower equivalent of 12 full-time employees. They also support the stations with funds covering equipment, consumables, travel and other expenses. The French station network receives additional grants directly from the Ministry of Research and Higher Education for either Research-Observation networks or the Future Investment Plan (PIA) from regional fundings, and from the national (French) ANR for international research projects.

Figure 16a

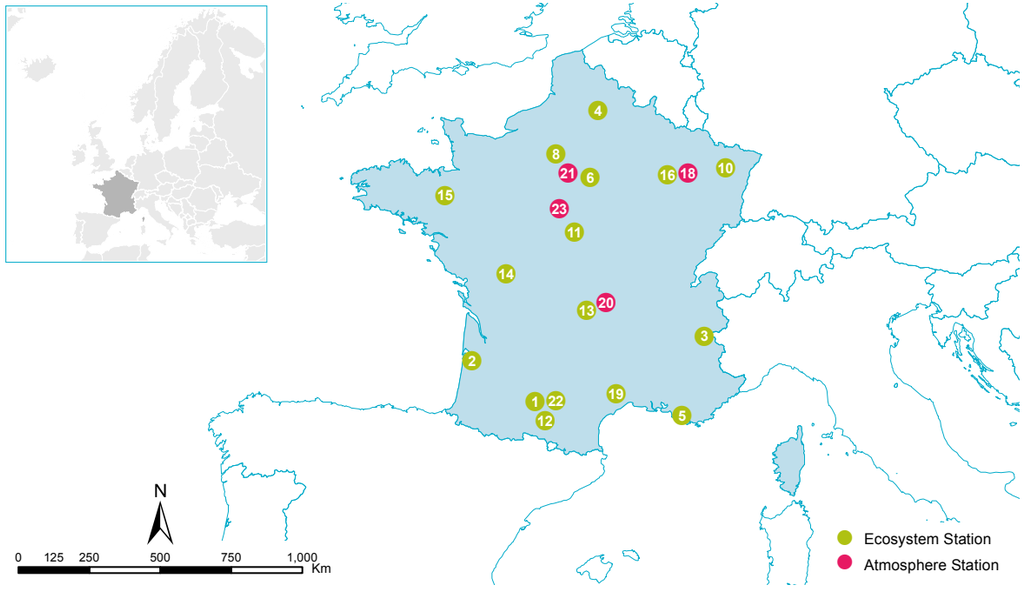


Figure 16b

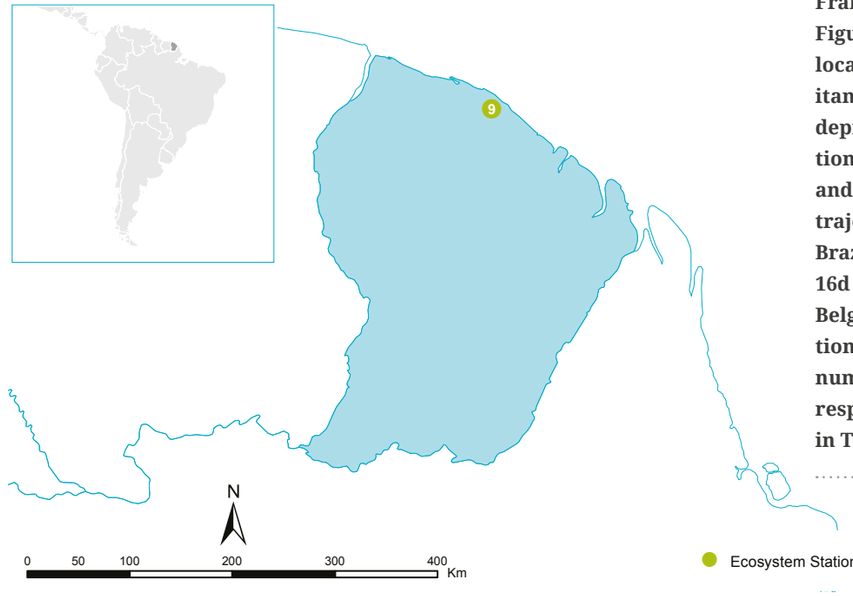


Figure 16: The ICOS France station network. Figure 16a shows stations located in the metropolitan France, Figure 16b depicts Ecosystem stations in French Guiana, and Figure 16c shows the trajectory of the France-Brazil SOOP route. Figure 16d shows the Franco-Belgian Atmosphere station in La Réunion. The numbers in the maps correspond to the numbers in Table 16.

Figure 16c

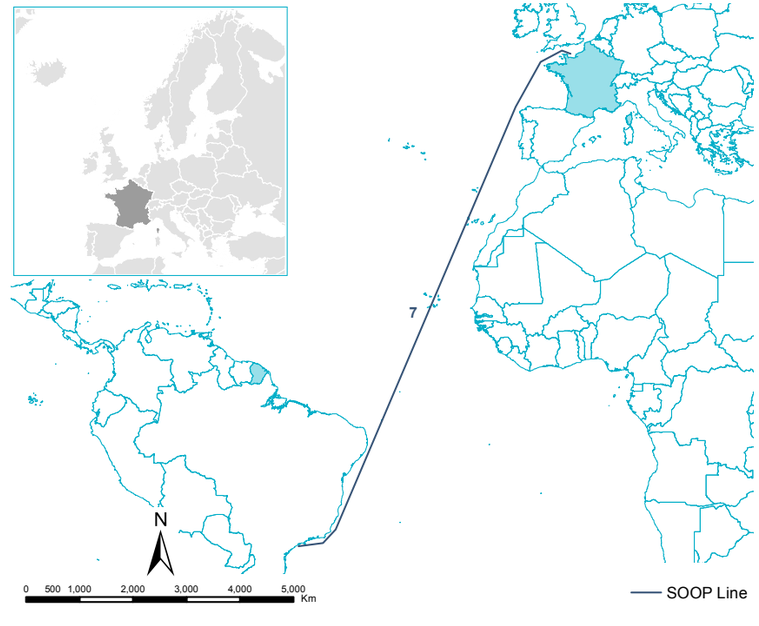
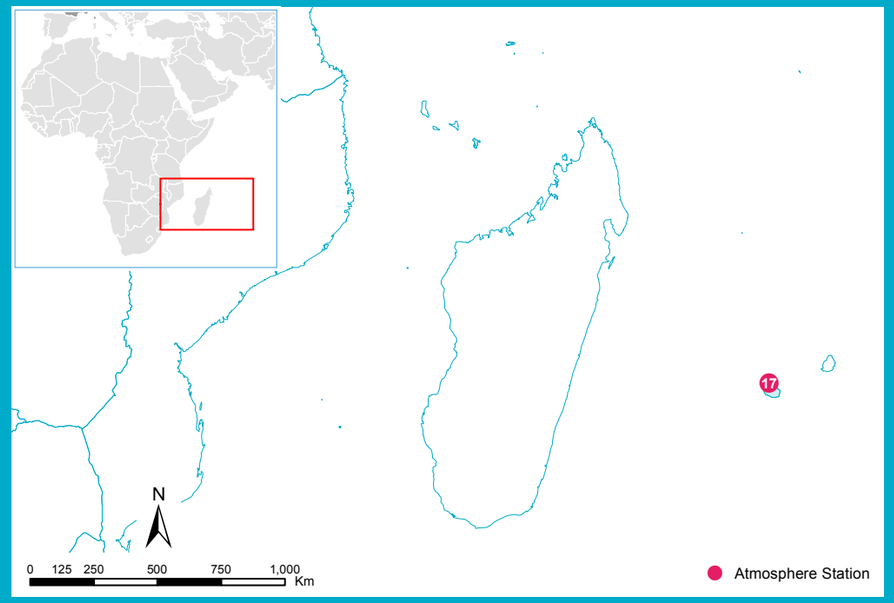


Figure 16d



ICOS FRANCE PARTNERS AND FUNDERS

Ministry of Higher Education, Research and Innovation
www.enseignementsup-recherche.gouv.fr

The National Centre for Scientific Research (CNRS; INSU and INEE)
www.cnrs.fr

French National Research Institute for Agriculture, Food, and Environment (INRAE)
www.inrae.fr/en

French Alternative Energies and Atomic Energy Commission (CEA)
www.cea.fr/english

French National Radioactive Waste Management Agency (ANDRA)
www.andra.fr

University of Versailles-Saint-Quentin-en-Yvelines (UVSQ)
www.uvsq.fr

Agro-ParisTech – Paris Institute of Technology for Life, Food and Environmental Sciences
www2.agroparistech.fr

Aix-Marseille University
www.univ-amu.fr/fr

Bordeaux-Sciences-Agro
www.agro-bordeaux.fr

French Geological Survey (BRGM)
www.brgm.eu

French Meteorological Institute
www.meteofrance.com

French National Museum of Natural History
www.mnhn.fr

French Polar Institute (IPEV)
www.institut-polaire.fr/language/en

French Research Institute for Development (IRD)
www.en.ird.fr

French Space Agency (CNES)
www.cnes.fr/en

Montpellier SupAgro, International Centre for Higher Education in Agricultural Sciences
www.montpellier-supagro.fr

National University of Ireland, Galway (Ireland)
www.nuigalway.ie

University of Abidjan (Côte d'Ivoire)
www.uniabidjan.com

University of Avignon
www.univ-avignon.fr

University of Clermont-Ferrand
www.en.uca.fr

University of Crete, Heraklion (Greece)
www.en.uoc.gr

University of French West Indies and Guiana
www.univ-ag.fr

University of Grenoble-Alpes
www.univ-grenoble-alpes.fr

University of La Paz, Bolivia

University of La Réunion Island
www.univ-reunion.fr

University of Lorraine
welcome.univ-lorraine.fr

University of Montpellier
www.umontpellier.fr

University of Orléans
www.univ-orleans.fr/en/international

University Paris-Saclay
www.universite-paris-saclay.fr/en

University Paul Sabatier, Toulouse
www.univ-tlse3.fr

University Paul Valéry of Montpellier III
www.univ-montp3.fr

University of Reims Champagne-Ardenne
www.univ-reims.eu

University Sorbonne, Paris
www.lettres.sorbonne-universite.fr

Table 16. ICOS stations in France

MAP NUMBER	STATION NAME	STATION ABBREVIATION	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
1	Auradé	FR-Aur	Ecosystem	Cropland	Associated	The National Centre for Scientific Research
2	Bilos - Salles	FR-Bil	Ecosystem	Forest	Class 2	French National Research Institute for Agriculture, Food, and Environment
3	Col-du-Lautaret	FR-Clt	Ecosystem	Grassland	Associated	The National Centre for Scientific Research
4	Estrées-Mons	FR-EM2	Ecosystem	Cropland	Associated	French National Research Institute for Agriculture, Food, and Environment
5	Font-Blanche	FR-FBn	Ecosystem	Forest	Class 2	French National Research Institute for Agriculture, Food, and Environment
6	Fontaine-bleau-Barbeau	FR-Fon	Ecosystem	Forest	Class 1	The National Centre for Scientific Research
7	France-Brazil	FR-SOOP-France-Brazil	Ocean	SOOP	Class 1	CNRS-IRD-U. Paris-Sorbonne
8	Grignon	FR-Gri	Ecosystem	Cropland	Class 2	French National Research Institute for Agriculture, Food, and Environment
9	Guyaflux	GF-Guy	Ecosystem	Forest	Associated	French National Research Institute for Agriculture, Food, and Environment
10	Hesse	FR-Hes	Ecosystem	Forest	Class 1	French National Research Institute for Agriculture, Food, and Environment
11	La Guette	FR-LGt	Ecosystem	Peatland	Associated	The National Centre for Scientific Research
12	Lamasquère	FR-Lam	Ecosystem	Cropland	Class 1	The National Centre for Scientific Research
13	Laqueuille	FR-Lqu	Ecosystem	Grassland	Class 2	French National Research Institute for Agriculture, Food, and Environment
14	Lusignan	FR-Lus	Ecosystem	Grassland	Class 2	French National Research Institute for Agriculture, Food, and Environment
15	Méjusseaume	FR-Mej	Ecosystem	Grassland	Associated	French National Research Institute for Agriculture, Food, and Environment
16	Montiers-sur-Saulx	FR-MsS	Ecosystem	Forest	Associated	French National Radioactive Waste Management Agency
17	Observatoire de l'Atmosphère du Maïdo	RUN	Atmosphere	Tall tower	Class 2	University of La Réunion
18	Observatoire Pérenne de l'Environnement	OPE	Atmosphere	Tall tower	Class 1	French National Radioactive Waste Management Agency
19	Puechabon	FR-Pue	Ecosystem	Forest	Class 2	The National Centre for Scientific Research
20	Puy de Dôme	PUY	Atmosphere	Mountain	Class 2	CEA-CNRS
21	Saclay	SAC	Atmosphere	Tall tower	Class 1	CEA-CNRS-UVSQ
22	Toulouse	FR-Tou	Ecosystem	Grassland	Associated	CNRM, University of Toulouse, Météo-France, CNRS
23	Trainou	TRN	Atmosphere	Tall tower	Class 1	CEA-CNRS

ICOS Germany

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Fendt: an Ecosystem station of ICOS Germany

The role of ICOS Germany

The ultimate goal of ICOS Germany is the long-term consolidation of the world's leading observation networks on atmospheric greenhouse gas concentrations and exchange fluxes within terrestrial and marine ecosystems. A dense station network covering important land-use types and the most common terrestrial ecosystems assure a high level of representative data sets and products for central Europe. These are complemented by crucial marine observations on different platforms for example in the Baltic Sea and in the North Atlantic Ocean.

Germany's featured station within the ICOScapes photo campaign was the Ecosystem site Fendt. Its location and site management represent the most typical farmland for the northern slopes of the Alps in Germany, Austria and Switzerland. These mountain regions are important for measurements because they are especially vulnerable to climate change. Over the last 50 years, the temperature in the Fendt station area has already risen twice as much as in the rest of Germany.

Germany also hosts one of the Central Facilities: the ICOS Central Analytical Laboratories. It is an ideal location due to its specific expertise in the high-precision analysis of trace gases, the provision of calibration standards for the observation networks, and in the analysis of the radioactive carbon isotope ^{14}C in air samples.

The tasks of the ICOS Germany coordination unit, the Thünen Institute of Climate-Smart Agriculture, include data integration, reporting and knowledge transfer among scientists, policymakers and the public.

The ICOS Germany infrastructure

ICOS Germany comprises 37 stations (Figures 17a, b; Table 17), and they are categorised into three station/observation networks: Atmosphere, Ecosystem and Ocean. The network is operated by 17 national research centres, universities and federal research institutions.

The Atmosphere station network covers the continuous monitoring of atmospheric greenhouse gas concentrations (CO_2, CH_4 and N_2O) combined with flask samples for their isotopic composition, radiocarbon sampling and tracer measurements (CO and ^{222}Rn) from a network of 12 observation stations at tall towers, and mountain and coastal stations distributed across Germany.

Continuous measurement of greenhouse gas fluxes (H_2O, CO_2, partly CH_4 and N_2O) between various ecosystems and the atmosphere are carried out in the Ecosystem station network of 20 stations with the use of the eddy covariance technique. The flux stations are mainly arranged in clusters, with different ecosystems being exposed to similar climatic conditions.

Measurements of greenhouse gas concentrations in the surface water and air-sea fluxes are carried out in the Ocean station network from two SOOP (Ship of Opportunity) lines in the North Atlantic Ocean and Baltic Sea in addition to the SOOP 'Polarstern' and at two oceanic time-series observatories at the polar (Hausgarten) and tropical (Cape Verde) extremes of the North Atlantic.

The ICOS Germany funding structure

ICOS Germany is funded by the German Federal Ministries for Digital and Transport (BMVI) and Education and Research (BMBF). Further funding is provided in-kind by the member institutions.

ICOS GERMANY PARTNERS AND FUNDERS

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (AWI)
www.awi.de/en.html

Technische Universität Dresden
www.tu-dresden.de

Federal Ministry of Education and Research (BMBF)
www.bmbf.de/en/index.html

Federal Ministry for Digital and Transport (BMVI)
www.bmvi.de/EN/Home/home.html

GEOMAR Helmholtz Centre for Ocean Research
www.geomar.de/en

Georg-August-University Göttingen
www.uni-goettingen.de

German Weather Service Deutscher Wetterdienst (DWD)
www.dwd.de/EN/Home/home_node.html

Heidelberg University
www.uni-heidelberg.de

Helmholtz Centre for Environmental Research, Leipzig (UFZ)
www.ufz.de

Forschungszentrum Jülich (FZJ)
www.fz-juelich.de

Karlsruhe Institute of Technology (KIT)
www.kit.edu/english

Max-Planck-Institute for Biogeochemistry (MPI)
www.bgc-jena.mpg.de

The Leibniz Institute for Baltic Sea Research (IOW)
www.io-warnemuende.de

Technische Universität Berlin
www.tu.berlin/en

Thünen Institute
www.thuenen.de/en

Weihenstephan-Triesdorf University of Applied Sciences
www.hswt.de

University of Freiburg
www.uni-freiburg.de

Landesbetrieb Forst Brandenburg
forst.brandenburg.de/lfb/de

Umweltbundesamt (UBA)
www.umweltbundesamt.de/en

Figure 17a

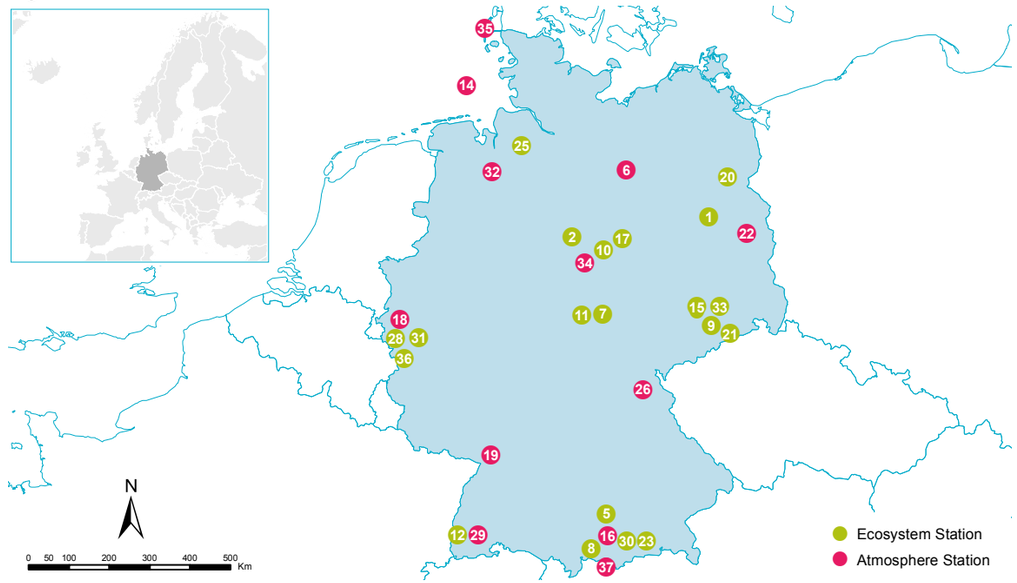

Figure 17b

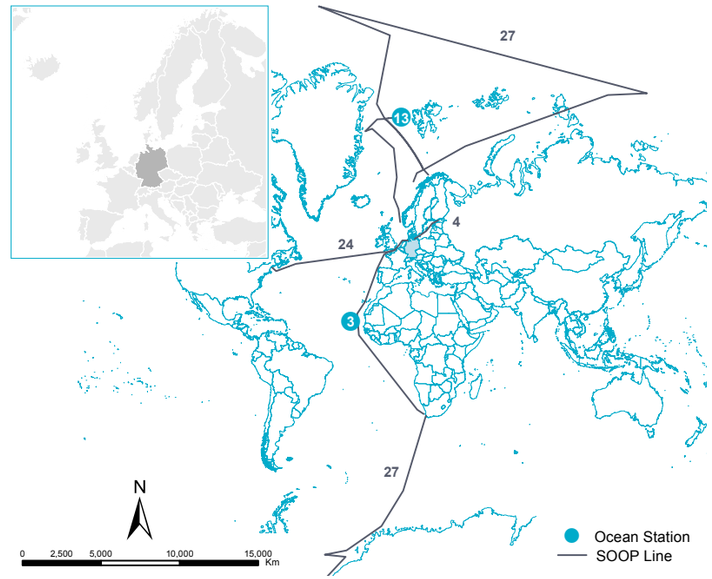

Figure 17: The ICOS Germany station network. Figure 17a shows the stations in mainland Germany, while Figure 17b depicts remote Ocean stations and SOOP lines. The numbers in the maps correspond to the numbers in Table 17.

Table 17. ICOS Stations in Germany

MAP NUMBER	STATION NAME	STATION ABBREVIATION	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
1	Berlin	*	Ecosystem	Urban	Associated	Technische Universität Berlin
2	Braunschweig	DE-Brs	Ecosystem	Cropland	Associated	German Weather Service (DWD)
3	Cape Verde Ocean Observatory	DE-FOS-CVOO	Ocean	Profiling station	Class 1	GEOMAR - Helmholtz Centre for Ocean Research Kiel
4	Finnmaid	DE-SOOP-Finnmaid	Ocean	SOOP line	Class 1	Leibniz Institute for Baltic Sea Research Warnemünde
5	Fendt	DE-Fen	Ecosystem	Grassland	Class 1	Karlsruhe Institute of Technology
6	Gartow	GAT	Atmosphere	Tall tower	Class 1	German Weather Service (DWD)
7	Gebesee	DE-Geb	Ecosystem	Cropland	Class 1	Thünen Institute of Climate-Smart Agriculture
8	Graswang	DE-Gwg	Ecosystem	Grassland	Associated	Karlsruhe Institute of Technology
9	Grillenburg	DE-Gri	Ecosystem	Grassland	Associated	Technische Universität Dresden
10	Am Grossen Bruch	DE-GsB	Ecosystem	Grassland	Associated	Helmholtz Centre for Environmental Research
11	Hainich	DE-Hai	Ecosystem	Deciduous forest	Associated	Georg-August-University Göttingen
12	Hartheim	DE-Har	Ecosystem	Coniferous forest	Associated	University of Freiburg
13	Hausgarten	DE-FOS-Hausgarten	Ocean	Profiling station	Class 1	Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (AWI)
14	Helgoland	HEL	Atmosphere	Tall tower	Class 2	German Weather Service (DWD)
15	Hetzdorf	DE-Hzd	Ecosystem	Plantation forest (oaks)	Associated	Technische Universität Dresden
16	Hohenpeissenberg	HPB	Atmosphere	Tall tower	Class 1	German Weather Service (DWD)
17	Hohes Holz	DE-HoH	Ecosystem	Deciduous forest	Class 1	Helmholtz Centre for Environmental Research
18	Jülich	JUE	Atmosphere	Tall tower	Class 2	German Weather Service (DWD)
19	Karlsruhe	KIT	Atmosphere	Tall tower	Class 1	German Weather Service (DWD)

Table 17. ICOS Stations in Germany

MAP NUMBER	STATION NAME	STATION ABBREVIATION	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
20	Kienhorst	DE-Kie	Ecosystem	Coniferous forest	Associated	Landesbetrieb Forst Brandenburg
21	Klingenberg	DE-Kli	Ecosystem	Cropland	Associated	Technische Universität Dresden
22	Lindenberg	LIN	Atmosphere	Tall tower	Class 1	German Weather Service (DWD)
23	Mooseurach	DE-Msr	Ecosystem	Coniferous bog forest	Associated	Weihenstephan-Triesdorf University of Applied Sciences
24	NA-SOOP	DE-SOOP-Atlantic Sail	Ocean	SOOP line	Class 1	GEOMAR - Helmholtz Centre for Ocean Research Kiel
25	Oberklenkendorf	DE-Okd	Ecosystem	Grassland	Associated	Thünen Institute of Climate-Smart Agriculture
26	Ochsenkopf	OXK	Atmosphere	Tall tower	Class 1	German Weather Service (DWD)
27	Polarstern	DE-SOOP-Polarstern	Ocean	Ship of Opportunity	Class 1	Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (AWI)
28	Rollesbroich	DE-RuR	Ecosystem	Grassland	Associated	Forschungszentrum Jülich (FZJ)
29	Schauinsland	SSL	Atmosphere	Mountain station	Class 1	Umweltbundesamt (UBA)
30	Schechenfilz	DE-SfN	Ecosystem	Coniferous bog forest	Associated	Karlsruhe Institute of Technology
31	Selhausen Jülich	DE-RuS	Ecosystem	Cropland	Class 1	Forschungszentrum Jülich (FZJ)
32	Steinkimmen	STE	Atmosphere	Tall tower	Class 1	German Weather Service (DWD)
33	Tharandt	DE-Tha	Ecosystem	Coniferous forest	Class 1	Technische Universität Dresden
34	Torfhaus	TOH	Atmosphere	Tall tower	Class 2	German Weather Service (DWD)
35	Westerland	WES	Atmosphere	Coastal station	Class 2	Umweltbundesamt (UBA)
36	Wüstebach	DE-RuW	Ecosystem	Coniferous forest	Associated	Forschungszentrum Jülich (FZJ)
37	Zugspitze	ZSF	Atmosphere	Mountain station	Class 2	Umweltbundesamt (UBA)

* To be determined later

ICOS Hungary

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Hegyhátsál: An Atmosphere station of ICOS Hungary

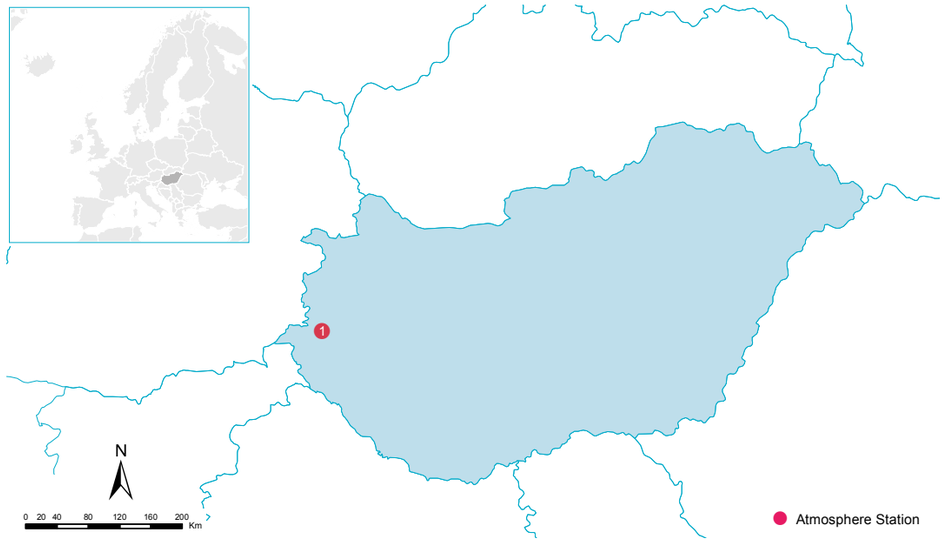
The role of ICOS Hungary

The main goal of ICOS Hungary is to expand the geographical coverage of the ICOS network towards the east. As Hungary is located in the zone of westerlies winds in Europe, adding measurement stations east of the existing ICOS network may significantly reduce the uncertainty of the continental atmospheric budget models. Hungary expands the long-term data series with its in situ atmospheric carbon dioxide measurements that date back to as early as 1981. Hungary has joined ICOS in January 2022.

The ICOS Hungary infrastructure

ICOS Hungary network consists of one Atmosphere Class 2 station, Hegyhátsál (Figure 18; Table 18). The instrumentation in this station, established in 1993, is mounted on a 117 m tall TV/radio transmitter tower owned by Antenna Hungária Corporation. ICOS Hungary activities are coordinated by the Institute for Nuclear Research (ATOMKI) that has a long tradition in environmental monitoring.

Figure 18: The ICOS Hungary station network. The numbers in the map correspond to the numbers in Table 18.



Hegyhátsál's monitoring program has been gradually expanded, and it has participated in several EU-funded international research projects throughout the years. The station also belongs to the global cooperative flask air sampling network of the US National Oceanic and Atmospheric Administration, and is a member of the Global Atmosphere Watch program of the World Meteorological Organization. Hegyhátsál measures in situ carbon dioxide and methane concentrations as well as basic meteorological variables. In addition, the station measures radiocarbon, carbon monoxide and vertical fluxes of nitrous oxide.

ICOS Hungary consortium will be developed gradually to involve university departments, the Hungarian Meteorological Service, and other institutions that are active in the field of atmospheric and ecosystem monitoring. In the coming years, two or more Ecosystem stations will also join the Hungarian network. The potential Ecosystem stations will focus on measuring the greenhouse gas budget of temperate climate zone grasslands. After that, the network will expand to include a second Atmosphere tall-tower in the eastern part of Hungary.

The ICOS Hungary funding structure

The common basic and GNI-based contributions, as well as the station-based contribution are paid by the National Research, Development and Innovation Office of Hungary (NKFIH). The development and running costs of the Hegyhátsál Atmosphere measurement station are covered by the Institute for Nuclear Research (ATOMKI).

ICOS HUNGARY PARTNERS AND FUNDERS

Institute for Nuclear Research (ATOMKI)
www.atomki.hu

Eötvös Loránd University
nimbus.elte.hu/research.html

Hungarian Meteorological Service
www.met.hu/en

Hungarian University of Agriculture and Life Sciences
uni-mate.hu

Institute of Earth Physics and Space Science
epss.hu/en

Table 18. ICOS stations in Hungary

MAP NUMBER	STATION NAME	STATION ABBREVIATION	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
1	Hegyhátsál	HUN	Atmosphere	Tall tower	Class 2	Institute for Nuclear Research (ATOMKI)

ICOS Italy

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Castelporziano 2: an Ecosystem station of ICOS Italy

The role of ICOS Italy

The international scientific community has shown that in the different domains (Atmosphere, Ecosystem and Ocean) of ICOS, the impacts, the responses and the mitigation capacity may differ from what has been assumed so far. For example, a significant impact of climate change on the biodiversity of natural ecosystems and/or on the productivity of agro-ecosystems can be assumed. In Italy, this problem appears particularly important given the multiplicity and diversity of its ecosystems, the circulation of air masses and seas in the various climatic zones and the vulnerability of most of them.

Italy hosts the southernmost ICOS stations in mainland Europe. Among these stations, Castelporziano hosts several forest ecosystems. One of these is the holm oak forest, which is, from the research perspective one of the most relevant types of ecosystems in the lower Mediterranean areas. ICOS observations at the Castelporziano station help in understanding how this type of forest is behaving in response to changes caused by rising temperatures. In addition, the station's closeness to the centre of Rome gives a better understanding of complex interactions between the urban environment and the plants. Moreover, the national network also includes the typical agroecosystems (e.g. vineyards and crops), which represent an important component of the Mediterranean landscape.

Italy leads the Ecosystem Thematic Centre (ETC).

The ICOS Italy infrastructure

ICOS Italy Joint Research Unit is coordinated by the National Research Council (CNR). ICOS Italy includes stations belonging to the three domains: Atmosphere, Ecosystem, and Ocean. In particular, ICOS Italy network consists of 17 stations (Figure 19; Table 19a), of which three are Atmosphere stations, ten are Ecosystem stations (two of Class 1, two of Class 2 and six Associated) and four are Ocean stations.

The Euro-Mediterranean Center on Climate Change and the University of Tuscia host the Ecosystem Thematic Centre (ETC) together with the University of Antwerp in Belgium and the French National Research Institute for Agriculture, Food and Environment (INRAE).

Thanks to the project 'Upgrading ICOS Italy Observation Network in the Mediterranean (PRO-ICOS_MED)', many stations, especially those based in the South of Italy, are being upgraded with state-of-the-art instrumentation and with the aim of linking ICOS protocols with advanced related measurements in line with the ICOS 2.0 strategic plan. As part of PRO-ICOS_MED, new Atmosphere (Potenza) and Ecosystem (Collelongo) stations are being built, while the Atmosphere station of Lampedusa is being implemented to become the only station in which all three domains of the ICOS network (Atmosphere, Ecosystem, Ocean) will be monitored simultaneously. In addition, hub of sensors and mobile units for the three domains are under construction to support the entire national network in the event of failures or maintenance / calibration operations, ensuring continuity and quality of the surveys over time.

The ICOS Italy funding structure

The main Italian funds derive from the Ministry of University and Research, which funds the Joint Research Unit through the Coordinator, CNR. Single partners receive funds for the various stations through international, national and local projects. Each partner institution supports ICOS through in-kind funding, mainly characterised by personnel and owned instrumentation.

Figure 19: The ICOS Italy station network. Atmosphere station Ispra (IPR) and Ecosystem station San Rossore 2 (IT-SR2) are run by the EU Joint Research Centre and they are highlighted on the map. The numbers in the map correspond to the numbers in Tables 19a and 19b.

ICOS ITALY PARTNERS AND FUNDERS

Autonomous Province of Bolzano-Alto Adige/Bozen-Südtirol
www.provinz.bz.it/de/default.asp

Catholic University of the Sacred Heart of Brescia
www.unicatt.it

Council for Agricultural Research and the Analysis of the Agrarian Economy (CREA)
www.crea.gov.it/it

Edmund Mach Foundation
www.fmach.it

Environmental Protection Agency of Aosta Valley (ARPA Valle d'Aosta)
www.arpa.vda.it

Euro-Mediterranean Center on Climate Change (CMCC)
www.cmcc.it

Free University of Bozen-Bolzano
www.unibz.it

Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)
www.enea.it

National Research Council (CNR), Department of Earth System Sciences and Environmental Technologies
www.dta.cnr.it/index.php/it

Ministry of University and Research (MUR)
www.mur.gov.it/it

National Institute of Oceanography and Applied Geophysics (OGS)
www.ogs.trieste.it/en

Research on Energy Systems - RSE S.p.A
www.rse-web.it

University of Genoa
www.unige.it

University of Padova
www.unipd.it/en

University of Sassari
www.uniss.it

University of Udine
www.uniud.it

University of Tuscia
www.unitus.it

Table 19a. ICOS Stations in Italy

MAP NUMBER	STATION NAME	STATION ABBREVIATION	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
1	Arca di Noe – Le Prigionette	IT-Noe	Ecosystem	Shrubland	Associated	University of Sassari
2	Borgo Cioffi	IT-BCi	Ecosystem	Cropland	Class 1	National Research Council – Institute for Agricultural and Forest Systems in the Mediterranean (ISAFOM)
3	Bosco Fontana	IT-BFt	Ecosystem	Oak-Hornbeam forest	Associated	Catholic University of the Sacred Heart of Brescia
4	Castelporziano 2	IT-Cp2	Ecosystem	Mediterranean forest	Class 1	Council for Agricultural Research and Economics (CREA)
5	E2M3A	IT-FOS-E2M3A	Ocean	Surface buoy	Class 2	National Institute of Oceanography and Applied Geophysics (OGS) - Section of Oceanography
6	Lampedusa	Lmp	Atmosphere	Open ocean	Class 2	National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)
7	Lison	IT-Lsn	Ecosystem	Vineyard	Associated	University of Padova and University of Udine
8	Miramare	IT-FOS-Miramare	Ocean	Surface buoy	Class 2	Oceanography and Applied Geophysics (OGS) - Section of Oceanography
9	Monte Bondone	IT-MBo	Ecosystem	Grassland	Class 2	Edmund Mach Foundation
10	Monte Cimone	IT-CMN	Atmosphere	Mountain peak	Class 2	Italian Air Force and National Research Council – Institute of Atmospheric Sciences and Climate (ISAC)
11	Nivolet	IT-Niv	Ecosystem	Alpine grassland	Associated	National Research Council – Institute of Geosciences and Earth Resources (IGG)
12	PALOMA	IT-FOS-PALOMA	Ocean	Beacon	Class 1	National Research Council-Institute of Marine Science (ISMAR)
13	Parco Urbano di Capodimonte	IT-PCm	Ecosystem	Urban park	Associated	National Research Council – Institute of Research on Terrestrial Ecosystems (IRET)
14	Plateau Rosa	IT-PRS	Atmosphere	Mountain peak	Class 2	Research on Energy Systems – RSE S.p.A
15	Renon	IT-Ren	Ecosystem	Subalpine forest	Class 2	Forest Services of the Autonomous Province of Bolzano
16	Torgnon	IT-Tor	Ecosystem	Alpine grassland	Associated	Environmental Protection Agency of Aosta Valley (ARPA VdA)
17	W1M3A	IT-FOS-W1M3A	Ocean	Surface buoy	Class 2	National Research Council – Institute for the Study of Anthropic Impact and Sustainability in the Marine Environment (IAS)

Table 19b. Stations run by the EU Joint Research Centre (JRC)

MAP NUMBER	STATION NAME	STATION ABBREVIATION	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
18	Ispra	IPR	Atmosphere	Tall tower	Class 2	JRC
19	San Rossore 2	IT-SR2	Ecosystem	Forest	Class 2	JRC

ICOS Netherlands

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Loobos: an Ecosystem station of ICOS Netherlands

The role of ICOS Netherlands

The Netherlands is unique in Western Europe in its situation as a lowland delta, with high population density, intense agricultural and strong spatial clustering of urban and rural areas. ICOS Netherlands aims to ultimately establish high observational density and high-resolution inversion modelling, enabling the area-wide verification of greenhouse gas exchange.

The three ICOS stations in The Netherlands comprise one Ecosystem flux station and two Atmosphere stations with established long-records. Together they serve as anchor points in the European network, covering the greenhouse gas exchange of a characteristic forest type as well as concentration fields that represent a region wider than the Netherlands. At the same time, they are key stations in the country-wide Ruisdael Observatory focused on both greenhouse gas budgets, cloud formation, extreme weather and air pollution.

ICOS Netherlands also plays an important role in the Carbon Portal, providing a multitude of data services for all of Europe.

The ICOS Netherlands infrastructure

The Dutch Consortium ICOS Netherlands consists of ten universities and knowledge institutes: the VU University Amsterdam (coordination), the University of Groningen, the Energy Research Centre of the Netherlands (ECN), Wageningen University, Wageningen Environmental Research (Alterra), Utrecht University, the Royal Netherlands Meteorological Institute (KNMI), SRON Netherlands Institute for Space Research, the Royal Netherlands Institute of Sea Research (NIOZ), and TNO Research.

ICOS Netherlands is divided into two ICOS observation networks: Atmosphere and Ecosystem. The ICOS Netherlands network consists of three stations

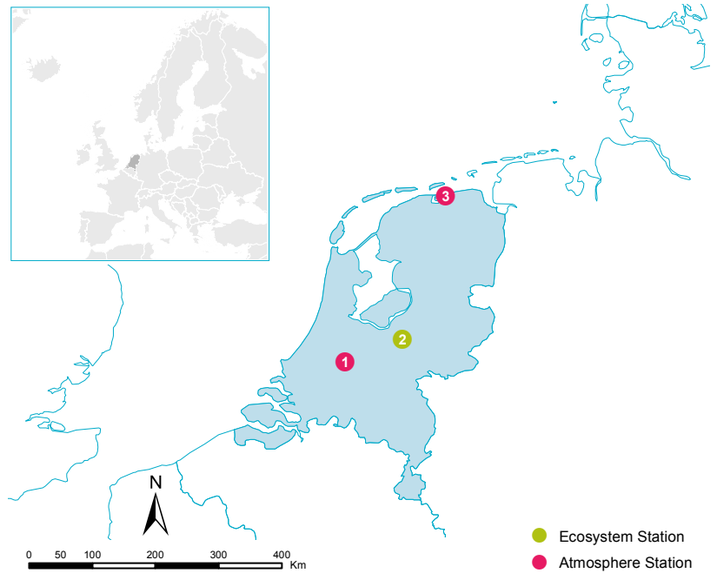

Figure 20: The ICOS Netherlands station network. The numbers in the map correspond to the numbers in Table 20.

(Figure 20; Table 20), of which two are Atmosphere stations and one is an Associate Ecosystem station. In addition, ICOS Netherlands makes a strong contribution to the ICOS Carbon Portal.

The Ecosystem station Loobos has entered the Class 2 labelling programme in 2021. However, it is one of the longest-running flux towers in Europe and also in the world. With regard to this 100-year-old pine forest, it has been producing continuous carbon and energy fluxes since 1996.

Of the two Atmosphere stations, Lutjewad is a 60-metre tower at the edge of the tidal Wadden sea/mud flats and the Cabauw tower is a 200-metre tall tower in the centre of the western Netherlands peat meadow and river deposits region, composed mainly of grazing land, but also including the city of Rotterdam in its footprint. Both of these stations have a long pre-ICOS history.

Recently, up to 15 fixed and 5 'mobile' Ecosystem and eddy covariance observation sites have been established to study GHG exchange of wetlands and peat meadow systems. With time, these will be integrated into the ICOS network.

The ICOS Netherlands funding structure

ICOS Netherlands is financially supported by the Ministry of Education, Culture and Science (OCW) and The Netherlands Organisation for Scientific Research (NWO). The ICOS Netherlands infrastructure is primarily funded through the large-scale Netherlands 'Ruisdael' observatory and the EU ATMO-ACCESS project 2021–2025, supplemented by matching funding from the host institutes. This observatory includes the three ICOS stations, other infrastructure linked to ACTRIS, other observation stations in the city of Rotterdam in addition to several mobile flux and concentration observation units (both terrestrial and airborne). The funding will provide the material and technical support for the network until about 2028.

ICOS NETHERLANDS PARTNERS AND FUNDERS

Ministry of Education, Culture and Science (OCW)
www.government.nl/ministries/ministry-of-education-culture-and-science

Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (TNO)
www.tno.nl

Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO)
www.nwo.nl/en

Royal Netherlands Institute of Sea Research (NIOZ)
www.nioz.nl/en

Royal Netherlands Meteorological Institute (KNMI)
www.knmi.nl/home

SRON Netherlands Institute for Space Research
www.sron.nl/

University of Groningen
www.rug.nl/

Wageningen University (WU)
www.wur.nl/

Utrecht University
www.uu.nl/en

Vrije Universiteit Amsterdam
www.vu.nl/en/

Table 20. ICOS Stations in the Netherlands

MAP NUMBER	STATION NAME	STATION ABBREVIATION	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
1	Cabauw	CES	Atmosphere	Tall tower	Class 1	KNMI/TNO
2	Loobos	NL-Loo	Ecosystem	Pine Forest	Class 2	University of Wageningen
3	Lutjewad	LUT	Atmosphere	Coastal/continental	Class 2	University of Groningen

ICOS Norway

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Ny-Ålesund and Kongsfjorden seen from the Zeppelin Observatory

The role of ICOS Norway

The long-term goal of ICOS Norway is to establish and operate an infrastructure that will allow for a complete accounting of carbon sources and sinks in the Arctic, North Atlantic, Norwegian and adjacent oceans. Measurements in the atmosphere, in the ocean and over land are combined to provide a basis for comprehensive carbon budgeting and to form a basis for the science underpinning policy actions.

ICOS Norway has a particularly strong ocean focus since it operates five of the 23 permanent Ocean stations and, together with the UK, hosts the Ocean Thematic Centre (OTC). Major scientific interests for ICOS Norway include the influence of the ocean on the greenhouse gas balance, and changes in the carbon cycle of the Arctic. Characterisation of the Arctic atmosphere and research on long-range atmospheric transport is facilitated through the uniquely-located Atmosphere station Zeppelin near Ny-Ålesund, Svalbard.

The ICOS Norway infrastructure

The ICOS Norway observation network consists of seven ICOS measurement stations (Figure 21; Table 21): five Ocean stations, two Atmosphere stations and one Ecosystem station. The Ocean domain measures CO_2 concentration in the surface ocean (used for quantifying the air-sea CO_2 flux), man-made CO_2 content and the rate of ocean acidification. The five Ocean stations are operated by the University of Bergen (UiB), the NORCE Norwegian Research Centre, and the Norwegian Polar Institute (NPI).

The Atmosphere domain, operated by the Norwegian Institute for Air Research (NILU), provides

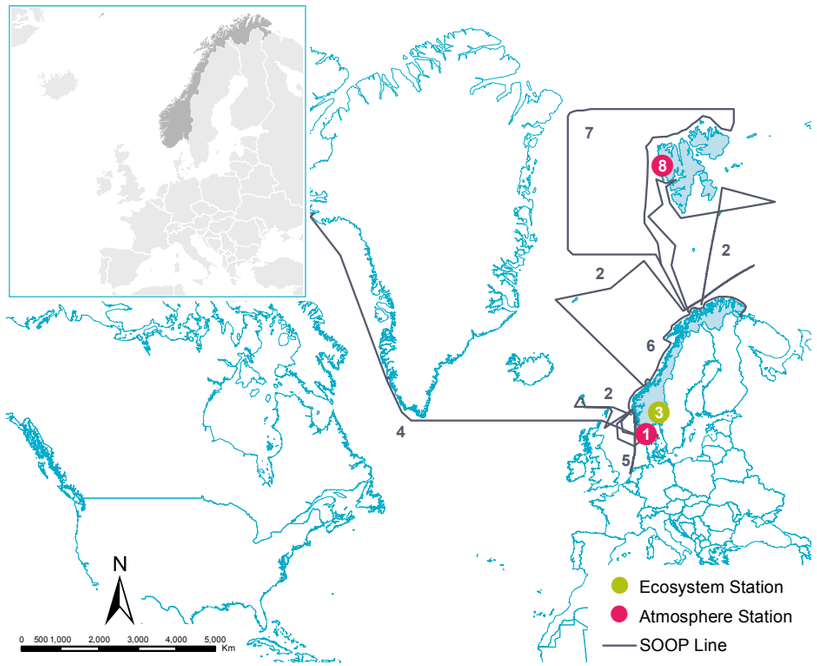

Figure 21: The ICOS Norway station network showing the stations located in mainland Norway, remote Atmosphere stations and SOOP lines. The numbers in the map correspond to the numbers in Table 21.

measurements of CO_2, CH_4, CO and N_2O in the atmosphere, which are used for understanding the changes and variations in these components in the long-term as well as at shorter timescales.

The Ecosystem domain measures the exchange and the uptake of carbon by the boreal forests in southern Norway and is operated by the Norwegian Institute of Bioeconomy Research (NIBIO). The ICOS Norway infrastructure, furthermore, carries out semi-operational estimates of CO_2 and CH_4 fluxes in Scandinavia through inverse modelling. Simulations are made by NILU, in collaboration with the Centre for International Climate and Environmental Research (CICERO), using ICOS data from Norway and Northern Europe as input.

The ICOS Norway funding structure

Implementation of the current ICOS Norway station network was funded by the Research Council of Norway (RCN). Upgrades to the station network are being funded via an RCN infrastructure project running from 2021–2024. This project also funds Norway's hosting of the Ocean Thematic Centre. Through this, the RCN has funded the implementation of ICOS methods and standards for Norwegian stations.

For the Ocean and Ecosystem domains, the RCN also funds operating costs, such as maintenance of the instruments, daily operations and data analysis. For the Atmosphere stations, these costs are covered through the institutes involved and various other projects. The main funding agencies for these activities are the Norwegian Ministry of Climate and Environment, the Norwegian Environmental Agency and the Research Council of Norway.

In October 2018, a proposal was submitted for funding to maintain and upgrade the ICOS Norway network in alignment with the next five-year financial period of ICOS (2020–2024). In April 2020, the RCN granted additional funding for the period of 2021–2023.

ICOS NORWAY PARTNERS AND FUNDERS

Centre for International Climate and Environmental Research (CICERO)
www.cicero.oslo.no/en

Institute for Marine Research (IMR)
www.imr.no/en

NORCE Norwegian Research Centre
www.norceresearch.no/en/

Norwegian Institute for Air Research (NILU)
www.nilu.no/

Norwegian Institute of Bioeconomy Research (NIBIO)
www.nibio.no/en

Norwegian Institute for Water Research (NIVA)
www.niva.no/en

Norwegian Polar Institute
www.npolar.no/en/

Royal Norwegian Ministry of Climate and Environment, Department for Nature Management
www.regjeringen.no/en/dep/kld/organisation/departments/department-nature-management/

The Research Council of Norway
www.forskningsradet.no/

University of Bergen
www.uib.no/en

Table 21. ICOS Stations in Norway

MAP NUMBER	STATION NAME	STATION ABBREVIATION	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
1	Birkenes Observatory	BIR	Atmos-phere	Hilly forest, meadow, lakes	Class 2	Norwegian Institute for Air Research
2	G. O. Sars	NO-SOOP-G.O.Sars	Ocean	SOOP, Nordic Seas	Class 1	NORCE Norwegian Research Centre
3	Hurdal	NO-Hur	Ecosystem	Norway spruce forest	Class 2	Norwegian Institute of Bioeconomy Research
4	MV Tukuma	NO-SOOP-Tukuma Arctica	Ocean	SOOP, northern North Atlantic	Class 1	University of Bergen
5	MV Trans Carrier	NO-SOOP-Trans Carrier	Ocean	SOOP, North Sea	Class 2	NORCE Norwegian Research Centre
6	Norwegian Coast-al Steamer – Bergen Kirkenes	NO-SOOP-Bergen Kirkenes	VOS, Norwegian Sea	Ocean	*	Norwegian Institute for Water Research
7	RV Kronprins Haakon	NO-SOOP-Kron-prins Haakon	Ocean	SOOP, Arctic Ocean	Class 2	Norwegian Polar Institute
8	Zeppelin Observatory	ZEP	Atmos-phere	Remote arctic, moun-tainous	Class 1	Norwegian Institute for Air Research

* To be determined later

ICOS Spain

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ESTOC: a future Ocean station of ICOS Spain

The role of ICOS Spain

The main goal of ICOS Spain is to considerably expand the geographical coverage of the ICOS RI observations in all three observation domains. The ICOS Spain station network covers Southwestern Europe, extending the ICOS observations to the subtropical North Atlantic on the Canary Islands. The Spanish infrastructure also provides GHG observations in the Mediterranean basin and in the North Atlantic. This includes the Strait of Gibraltar where the connection of the two seas leads to a significant exchange of air and water masses.

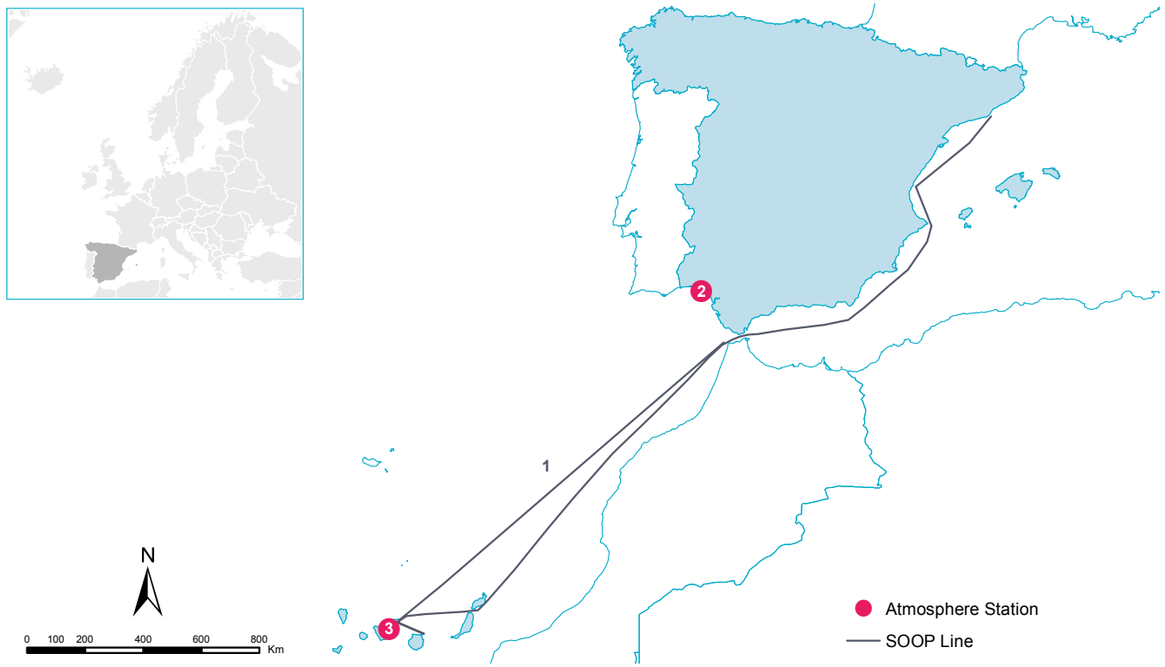
The Spanish Atmosphere stations contribute to unique background measurements of GHGs. These stations include, for instance, the historical Izaña Atmosphere station, located in Tenerife, the Canary Islands. The station has records of CO_2 and CH_4 measurements since 1984.

The ICOS Spain infrastructure

The ICOS Spain infrastructure is coordinated by the State Meteorological Agency of Spain (AEMET), participating the QUIMA group of the Instituto de Oceanografía y Cambio Global – University of Las Palmas de Gran Canaria (ULPGC), the Oceanic Platform of the Canary Islands (PLOCAN), the Spanish Institute of Oceanography (IEO) and the National Institute of Aerospace Technology (INTA). These partners have a leading role in climate modelling and research, and regional greenhouse gas measurements in Spain.

ICOS Spain comprises three stations, of which two are Atmosphere stations and one is an Ocean station. Most of the stations are integrated to several existing international observation networks. For example, the Izaña Atmosphere station belongs to the Total Carbon Column Observing Network (TCCON)

Figure 22: Future ICOS Spain station network. The numbers in the map correspond to the numbers in Table 22.



and the COllaborative Carbon Column Observing Network (COCCON). Several of the stations are co-located with other research infrastructures such as the European Research Infrastructure for the observation of Aerosol, Clouds and Trace Gases (ACTRIS).

The Izaña Atmosphere station has a long and globally important history of background reference CO_2 and CH_4 measurements. The station belongs to the WMO GAW program and runs quality control/assurance audits conducted by the Swiss Federal Laboratories for Materials Science and Technology (Empa).

The mainland Atmosphere station of El Arenosillo located in southwest provides important information on the air mass transport from the Atlantic Ocean and the Western Mediterranean.

The CanOA VOS-line operates between the Canary Islands and Barcelona through the Strait of Gibraltar and the West Mediterranean Sea. In the future, it will be complemented with the ESTOC Ocean station in the north of the Canary Islands.

The ICOS Spain funding structure

The main Spanish funds derive from the State Meteorological Agency (AEMET) that is attached to the Ministry for Ecological Transition and Demographic Challenge (MITECO). Further funding is provided by the partner institutions, mostly as in-kind voluntary contributions covering personal, equipment, consumables and travel costs.

A LIST OF ICOS SPAIN PARTNERS AND FUNDERS

State Meteorological Agency of Spain (AEMET)
www.aemet.es/en

QUIMA group, Instituto de Oceanografía y Cambio Global – University of Las Palmas de Gran Canaria (ULPGC)
iocag.ulpgc.es/research/research-units/quima

National Institute of Aerospace Technology (INTA)
www.inta.es

Oceanic Platform of the Canary Islands (PLOCAN)
www.inta.es

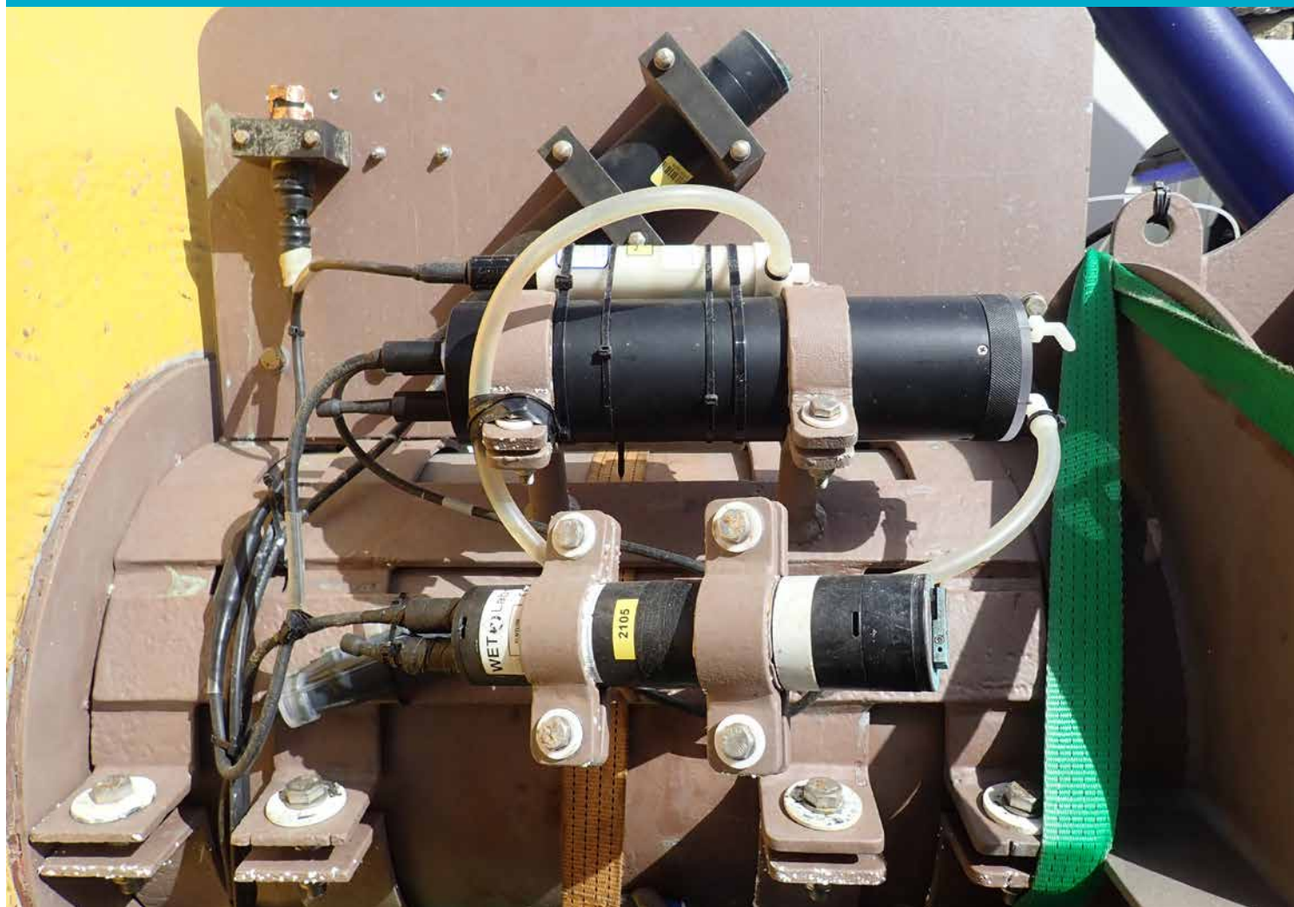
National Research Council (CSIC), Spanish Institute of Oceanography (IEO)
iocag.ulpgc.es/research/research-units/quima

Ministry for Ecological Transition and Demographic Challenge (MTERD)
www.miteco.gob.es/en

Table 22. ICOS Spain stations network

MAP NUMBER	STATION NAME	STATION ABBREVIATION	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
1	CanOA VOS-line	ES-CAN	Ocean	VOS, Atlantic Ocean	Class 1	University of Las Palmas de Gran Canaria
2	El Arenosillo	*	Atmosphere	Tall Tower	Class 2	National Institute of Aerospace Technology
3	Izaña	IZO	Atmosphere	Mountain	Class 2	State Meteorological Agency of Spain

* To be determined later



ICOS Sweden

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Svartberget: a combined Atmosphere and Ecosystem station of ICOS Sweden

The role of ICOS Sweden

ICOS Sweden contributes with a national observation network covering the full latitudinal extent of Sweden, consisting of six Ecosystem stations (three forests, and three mires), three Atmosphere stations, and two Ocean stations. These stations are essential for ICOS, as they provide otherwise scarce data from northern latitudes, which are undergoing the fastest climate change in the world. Climate warming could destabilise the carbon stored in boreal forest soils, accelerate the degradation of the mires and acidification of the seas, with a concomitant impact on Sweden's economy and commitment to enhance carbon sinks.

ICOS Sweden, as a national research infrastructure, aims at having a central role in the support of Swedish biogeochemistry research, at providing test sites for national inventory systems, and at providing sites and databases for advanced research. Furthermore, ICOS Sweden also aims at fostering collaboration and interoperability with other in situ environmental measurement networks and remote sensing programs active in Sweden, and at actively stimulating scientific studies and modelling efforts.

The ICOS Carbon Portal, which is part of the ICOS ERIC, is located in Sweden and it is run by Sweden in conjunction with the Netherlands. Carbon Portal acts as the platform for observational data and elaborated data products of the ICOS RI.

The ICOS Sweden infrastructure

ICOS Sweden is a national research infrastructure presently consisting of a consortium of six partners: Lund University, Gothenburg University, the Swedish University of Agricultural Sciences, Uppsala University, the Swedish Meteorological and Hydrological Institute, and the Swedish Polar Research Secretariat. Lund University hosts the consortium and the coordination office, with the director of ICOS Sweden also acting as the national Focal Point.

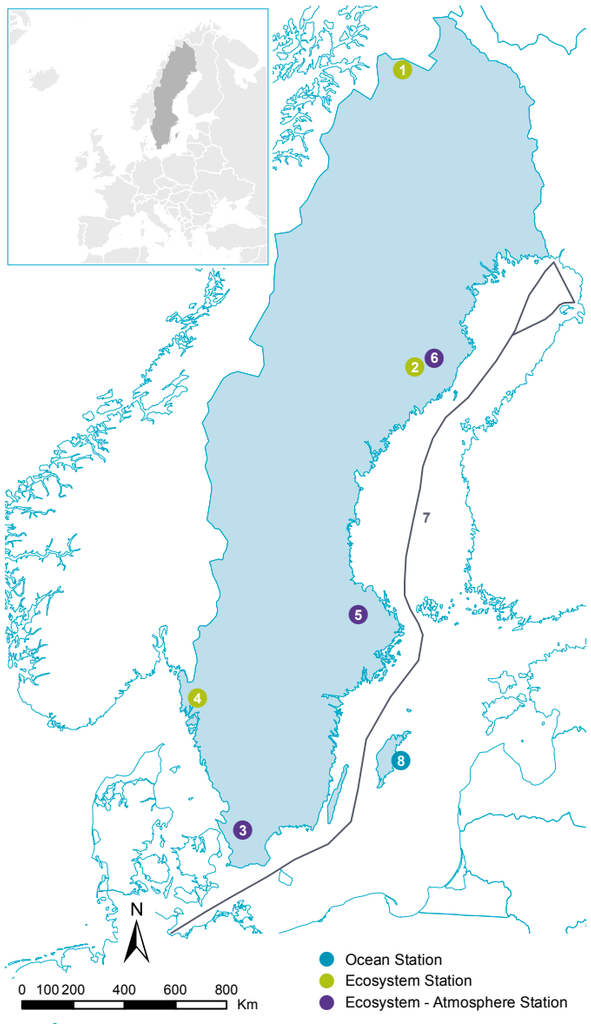
All the partners of ICOS Sweden have active roles in many subfields within atmospheric, marine, and earth systems science.

ICOS Sweden contributes to observations in all three ICOS observation networks. The ICOS Sweden network consists of 11 stations (Figure 23; Table 23), of which six are Ecosystem stations representing boreal forests and boreal to subarctic mires, and two are Ocean stations representing the Baltic Sea. The three Atmosphere stations are co-located with the three forest Ecosystem stations, representing a north-south gradient in the country.

The ICOS Sweden research infrastructure has been in operation at most Ecosystem stations since 2014. Three stations have long measurement records: Norunda Ecosystem station and Östergarnsholm since 1995, and Degerö since 2001. The Ecosystem stations primarily provide data on greenhouse gas concentrations and fluxes as well as latent and sensible heat fluxes. In addition, several meteorological and soil parameters and complementary ecosystem parameters are measured. The Atmosphere stations include tall-tower measurements of concentrations of greenhouse gases in the well-mixed boundary-layer. The Östergarnsholm Ocean station measures meteorological variables, together with the concentration and fluxes of CO_2 and other gases from ocean surface waters and the near-surface atmosphere. The M/S Tavastland SOOP provides continuous data of CO_2 and other oceanographic parameters along the bi-weekly Oulu-Kemi-Lübeck transect.

All three Atmosphere stations received the ICOS label in 2018. Hyltemossa, Norunda, Svartberget and Degerö Ecosystem stations received the ICOS label in 2018–2019. The remaining stations are expected to be labelled in 2022. Several stations are co-located with other RIs such as ACTRIS, SITES (a national RI for terrestrial and limnologic field research) and NordSpec (a research network for spectral data collection).

Figure 23: The ICOS Sweden station network. The numbers in the map correspond to the numbers in Table 23.



ICOS SWEDEN PARTNERS AND FUNDERS

Swedish Research Council
www.vr.se/english.html

Lund University
www.lunduniversity.lu.se

Swedish University of Agricultural Sciences
www.slu.se/en

Uppsala University
www.uu.se/en

University of Gothenburg
www.gu.se/english

Swedish Polar Research Secretariat
polar.se/en

Swedish Meteorological and Hydrological Institute
www.smhi.se/en

The ICOS Sweden funding structure

Funding for the construction and operations of ICOS Sweden is provided by the Swedish Research Council (SRC) and the consortium partners. The Swedish Research Council has covered 40–50% of the costs for the past and current (2021–2024) funding period, while the consortium partners together cover 50–60 percent of the costs.

Table 23. ICOS Stations in Sweden

MAP NUMBER	STATION NAME	STATION ABBREVIATION	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
1	Abisko-Stordalen Palsa Bog	SE-Sto	Ecosystem	Sub-arctic fen	Class 2	Swedish Polar Research Secretariat
2	Degerö	SE-Deg	Ecosystem	Boreal fen	Class 2	Swedish University of Agricultural Sciences
3	Hyltemossa	HTM	Atmos-phere	Tall tower	Class 1	Lund University
3	Hyltemossa	SE-Htm	Ecosystem	Temperate spruce	Class 2	Lund University
4	Mycklemossen	SE-Myc	Ecosystem	Hemi-boreal fen	Class 2	University of Gothenburg
5	Norunda	NOR	Atmos-phere	Tall tower	Class 1	Lund University
5	Norunda	SE-Nor	Ecosystem	Hemi-boreal pine/spruce	Class 2	Lund University
6	Svartberget	SVB	Atmos-phere	Tall tower	Class 1	Swedish University of Agricultural Sciences
6	Svartberget	SE-Svb	Ecosystem	Boreal pine/spruce	Class 2	Swedish University of Agricultural Sciences
7	Tavastland	SE-SOOP Tavastland	Ocean	SOOP, Baltic Sea	Class 1	Swedish Meteoro-logical and Hydro-logical Institute
8	Östergarnsholm	SE-MFT-Östergarnsholm	Ocean	Coastal Baltic Sea	Class 1	Uppsala University

ICOS Switzerland

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Jungfraujoch: the Atmosphere station of ICOS Switzerland

The role of ICOS Switzerland

The ICOS Switzerland consortium is part of ICOS RI with two Class 1 stations, Jungfraujoch and Davos. Both of them are unique in terms of their geographical location, site history and relevance for national and international research as well as policy advice. Since the Alpine region will be strongly affected by climate change, information about it is absolutely crucial. Adding an urban site will allow to address urban settings in the future. Thus, Switzerland, with its exceptional geographic location in the central part of the Alps and its measurement stations, is an outstanding node within the ICOS RI network.

The Swiss consortium builds on long-standing expertise in both atmospheric and ecosystem sciences. Thus, the Swiss ICOS stations are well embedded in various national and international programmes, and ICOS Switzerland is continuously working on increasing the value of its ICOS stations also beyond the ICOS network. For example, synergies with the Aerosols, Clouds and Trace Gases Research Infrastructure (ACTRIS) and the European Long-term Ecosystem Research Infrastructure (eLTER) are pursued, and close interactions with stakeholders are ensured.

The ICOS Switzerland infrastructure

The ICOS Switzerland consortium consists of ETH Zurich (National Focal Point), Empa, WSL, the University of Bern, the University of Basel, and MeteoSwiss. ICOS Switzerland contributes to ICOS RI with one Atmosphere station (Jungfraujoch) and one Ecosystem station (Davos) (Figure 24; Table 24).

Jungfraujoch (3,580 m a.s.l.) is the highest, permanently manned research station in Europe, and the highest measurement station in the ICOS network. Continuous in situ measurements of reactive gases started in Jungfraujoch in 1973, and measurements of greenhouse gases were initiated in 2000. Due to its elevation and distance from major greenhouse gas sources and sinks, Jungfraujoch station is mainly exposed to air masses representing pristine conditions, but occasionally also to air pollution, especially when air from lower atmospheric layers reaches the station. The information on the background conditions over Central Europe is of key importance in quantifying emission strengths in more polluted environments.

Davos is the only subalpine Norway spruce forest (1,639 m a.s.l.) within ICOS RI, and it is one of the oldest ecosystem flux sites globally. Its record of CO_2 and H_2O vapour flux measurements dates back to 1997. This allows detecting the impacts of slow climate change on the carbon sink capacity of this high elevation forest over time. Moreover, detailed functional, e.g. ecophysiological assessments allow to study how the forest responds to the extreme weather events that are predicted to increase in frequency due to climate change.

The future urban station in Basel (264 m a.s.l.), which has one of the longest urban CO_2 flux records worldwide (permanently operated since 2004), will play a significant role in comparing urban fluxes to background emissions detected at Jungfraujoch. Moreover, the long-term quantification of urban emissions by eddy covariance will allow responding to the scientific and political demand for reliable measurements of the most dynamic land cover globally.

The ICOS Switzerland funding structure

ICOS Switzerland had been funded by the European Commission (Preparatory Phase, 2008–2012), and since 2013 by the Swiss National Science Foundation, in-house contributions and the State Secretariat for Education, Research and Innovation (Phase 1: 2013–2017; Phase 2: 2017–2021, Phase 3: 2021-2025).

ICOS SWITZERLAND PARTNERS AND FUNDERS

Empa – Swiss Federal Laboratories for Material Sciences & Technology
www.empa.ch

ETH Zurich
www.ethz.ch

Federal Office for the Environment (FOEN)
www.bafu.admin.ch/bafu/en/home.html

Federal Office of Meteorology and Climatology (MeteoSwiss)
www.meteoswiss.admin.ch/home.html

International Foundation High Altitude Research Stations Jungfraujoch and Gornergrat (HFSJG)
www.HFSJG.ch

State Secretariat for Education, Research and Innovation (SERI)
www.sbfi.admin.ch/sbfi/en/home/seri/seri.html

Swiss Federal Institute for Forest, Snow and Landscape Research (WSL)
www.wsl.ch/en.html

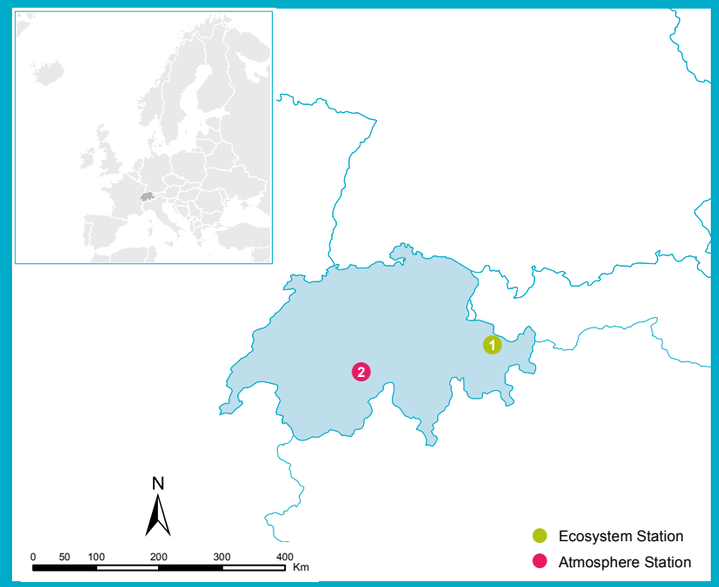
University of Basel
www.unibas.ch/en.html

University of Bern
www.unibe.ch/index_eng.html

Table 24. ICOS Stations in Switzerland

MAP NUMBER	STATION NAME	STATION ABBREVIATION	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
1	Davos	CH-Dav	Ecosystem	Subalpine forest	Class 1	ETH Zurich, Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Swiss Federal Laboratories for Material Sciences & Technology (Empa), National Air Pollution Monitoring Network (NABEL/FOEN)
2	Jungfraujoch	JFJ	Atmosphere	Alpine mountain	Class 1	High Altitude Research Stations Jungfraujoch & Gornergrat (HFSJG), University of Bern, Swiss Federal Laboratories for Material Sciences & Technology (Empa), National Air Pollution Monitoring Network (NABEL/FOEN), MeteoSwiss, University of Basel

Figure 24: The ICOS Switzerland station network. The numbers in the map correspond to the numbers in Table 24.



ICOS United Kingdom

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Auchencorth Moss: an Ecosystem station of ICOS UK

The role of ICOS UK

The Atmosphere Observation network of the ICOS United Kingdom (UK) is designed to allow the entire greenhouse gas budget of the UK to be determined and to quantify the impact of urban landscapes on this budget. The Ecosystem Observation network of ICOS UK is designed to account for the heterogeneity present in UK landscape types and climate, and it aims to sample the uptake of carbon by forests, peatlands and grasslands (the major ecotypes with significant impact on natural and anthropogenic greenhouse gas cycling). The Ocean Observation network of ICOS UK is designed to capture both the air-sea exchanges and the oceanic sinks of greenhouse gases.

By becoming a full member state within the ICOS network, the UK will benefit and play its part in the following ways: 1) contributing to developments and developing cutting-edge greenhouse gas measurement techniques and processes, 2) accessing up-to-date information on the activities within ICOS RI, 3) providing support with station instrumentation, protocols and training, 4) obtaining measurement data in a harmonised and processed pool of open world-class greenhouse gas databases, 5) accessing EU capital funding available through the EU Infrastructure Roadmap, and 6) accessing national capital funding available through the UK RI Roadmap.

ICOS UK coordinates the Ocean Thematic Centre in conjunction with Norway.

The ICOS UK infrastructure

ICOS UK is divided into three ICOS observation networks: Atmosphere, Ecosystem, and Ocean. The ICOS UK National Network consists of five stations

Figure 25: The ICOS UK station network. The numbers in the map correspond to the numbers in Table 25.

(Table 25; Figure 25). At present, ICOS UK has one Ecosystem station (Auchencorth Moss, led by the Centre of Ecology & Hydrology); two Atmosphere stations (Ridge Hill, led by the University of Bristol, and Weybourne, led by the University of East Anglia) and two Ocean stations: the Western Channel Observatory (led by Plymouth Marine Laboratory) and a buoy, the PAP-SO (maintained by the National Oceanography Centre).

Weybourne Atmospheric Observatory is a WMO GAW regional station operated by the University of East Anglia and funded by the National Centre for Atmospheric Science (NCAS). Measurements include CO_2, CH_4 and N_2O.

The PAP SO buoy (National Oceanography Centre), located at 49° N, 16.5° W, collects high frequency surface and sub-surface CO_2 data.

The Ridge Hill Atmosphere station (University of Bristol) measures greenhouse and ozone-depleting gases from tall telecommunication towers. High-frequency measurements of all major greenhouse gases are made at Ridge Hill, including CO_2, CH_4, NO, SF_6 and a suite of halocarbons. The data from the UK network are used to assess atmospheric trends and UK emissions of these gases.

The Western Channel Observatory is an oceanographic time-series and marine biodiversity reference site in the Western English Channel.

Auchencorth Moss is part of a sensitive peatland ecosystem in central southern Scotland. The latter is a valuable location for long-term monitoring of surface/atmospheric exchange fluctuations and measurements indicating environmental change.

The ICOS UK funding structure

The Natural Environment Research Council (NERC) funds UK institutions via the CLASS programme.

ICOS UK PARTNERS AND FUNDERS

Centre for Ecology and Hydrology
www.ceh.ac.uk

MET Office
www.metoffice.gov.uk

National Centre for Atmospheric Science
www.ncas.ac.uk/en

National Oceanography Centre (NOC) Southampton
www.noc.ac.uk

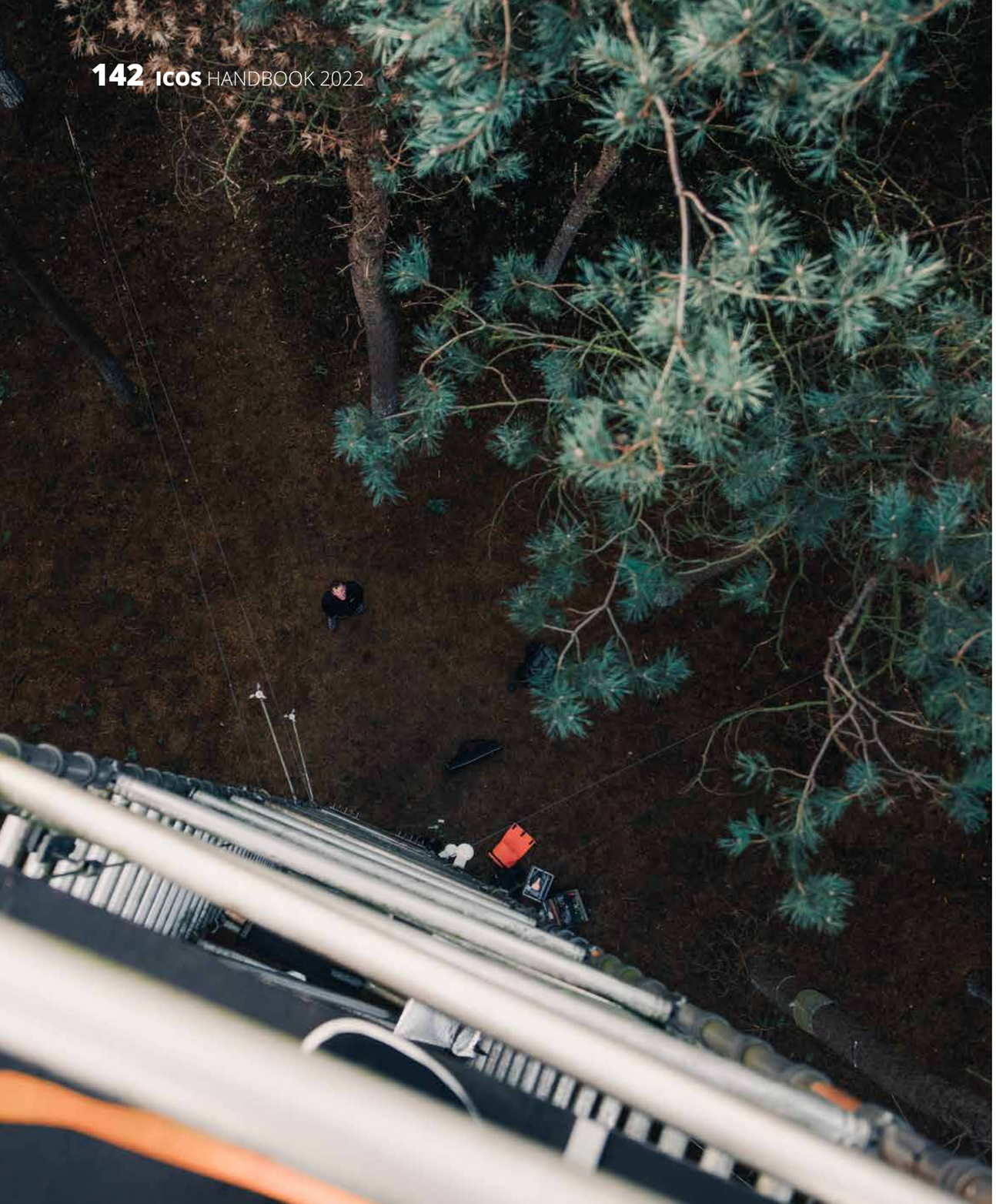
Plymouth Marine Laboratory (PML)
www.pml.ac.uk

University of Bristol
www.bristol.ac.uk

University of East Anglia
www.uea.ac.uk

Table 25. ICOS Stations in the United Kingdom

MAP NUMBER	STATION NAME	STATION ABBREVIATION	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
1	Auchencorth Moss	UK-AMo	Ecosystem	Peatland	Class 1	Centre for Ecology and Hydrology
2	PAP Sustained Observatory	UK-FOS-PAP	Ocean	Ocean mooring and surface buoy, NW Atlantic	Class 1	National Oceanography Centre (NOC) and the MET Office
3	Ridge Hill	RGL	Atmosphere	Tall tower	Class 2	University of Bristol
4	Western Channel Observatory	UK-FOS-Western Channel Observatory	Ocean	Ocean mooring and surface buoy, NW Atlantic	Class 1	Plymouth Marine Laboratory
5	Weybourne Atmospheric Observatory	WAO	Atmosphere	Coastal	Class 2	National Centre for Atmospheric Science and the University of East Anglia



8 PROSPECTIVE COUNTRIES: Future members of ICOS ERIC

The geographical extension of the ICOS measurement network is of crucial scientific importance. Atmospheric data over a larger area give information on air transport patterns, ecosystem data from a variety of biomes increase our understanding of carbon fluxes, as do new oceanic routes in different regions of the world. If member countries in ICOS are encouraged to develop their national networks of measurement stations, new countries are also welcome to contribute to this strategic enlargement. Every member country of the European Union as well as associated and third countries provided that certain legal requirements are met making them eligible to join ICOS ERIC, either as a member or an observer.

The more members in ICOS ERIC, the stronger the assets of the whole RI. The scientific community is larger and more diverse, the standardisation of data and protocols progresses, the cooperation between scientific organisations in Europe is fostered, the connection to similar international networks increases, the sustainability of the Research Infrastructure is improved.

Ireland, Poland and Romania are cooperating with ICOS in order to increase their readiness to become members of ICOS ERIC. Of these, Poland and Romania have announced their plans to join in 2023: they are presented on the following pages.

ICOS Poland

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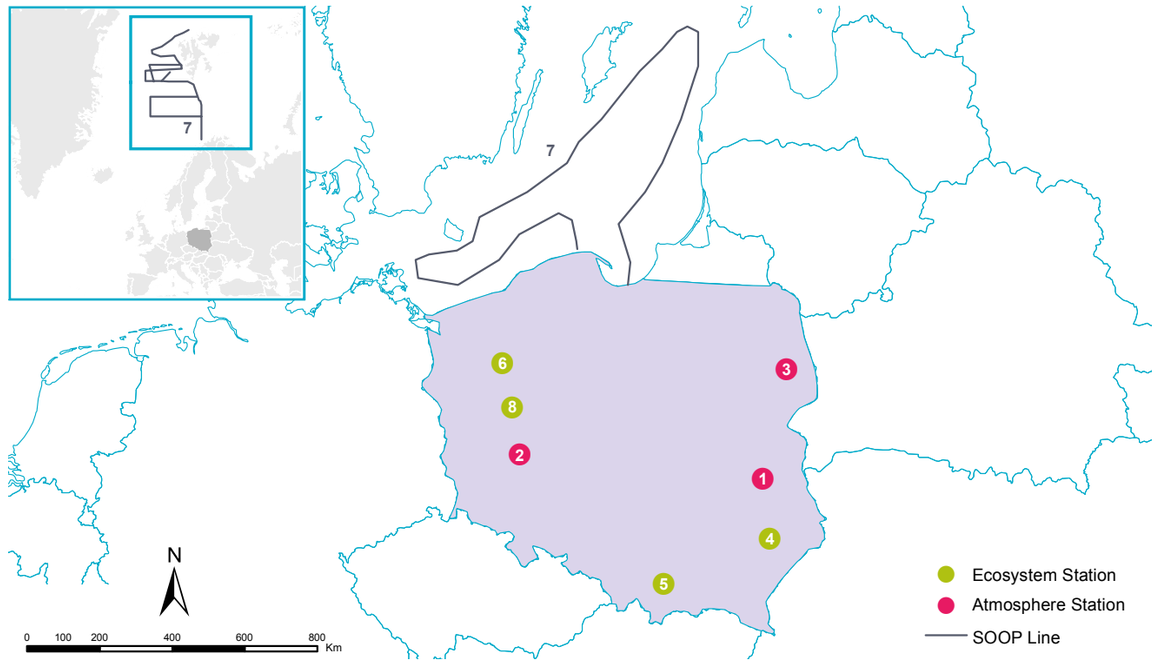
Mezyk: an Ecosystem station of future ICOS Poland

The role of ICOS Poland

The main goal of ICOS Poland is the long-term research of the carbon cycle with the focus on the greenhouse gas exchanges between the most representative terrestrial ecosystem types, the Baltic Sea and the atmosphere. Combining measurements of the atmosphere, ecosystems and the ocean, the ICOS Poland infrastructure enables to determine the effects of land use changes and climate variability in Poland.

Figure 26: Future ICOS Poland station network. The numbers in the map correspond to the numbers in Table 26.



The ICOS Poland infrastructure

ICOS Poland is hosted by a single institution, the Institute of Environment Protection (IOŚ) in Warsaw and operated by IOŚ together with four other scientific institutions and universities: the Institute of Agrophysics (IA PAN) and the Institute of Oceanology (IO PAN) of the Polish Academy of Sciences, the Poznań University of Life Sciences (PULS), and the University of Science and Technology (AGH).

ICOS Poland will eventually consist of eight stations, of which four are already operating (built during the CarboEurope/NitroEurope projects) and four stations will be built in the near future. These comprise four Ecosystem, three Atmosphere and one Ocean station (the Pomerania ship at the Baltic Sea). The Ecosystem stations are located in different ecosystems which partly represent the mosaic land-use structure in Poland: forest, agriculture and wetland. The urban station is situated in Kraków, the third largest city of Poland. The triangular placement of the Atmosphere stations covers a significant part of the Polish territory: two of the Atmosphere stations are located on the east side of Poland along the borders with Belarus and Ukraine, and the third Atmosphere station is in the middle west of Poland. It is planned that Poland will submit documents requesting to join ICOS ERIC in spring 2022.

The ICOS Poland funding structure

ICOS Poland will be funded by two ministries: the Ministry of Science and Higher Education (50% of total budget for the first 3 years) and the Ministry of Climate (50% for the next 12 years).

A LIST OF ICOS POLAND PARTNERS AND FUNDERS

Institute of Environment Protection (IOŚ)
ios.edu.pl

Institute of Agrophysics of the Polish Academy of Sciences (IA PAN)
www.ipan.lublin.pl/en

Institute of Oceanology of the Polish Academy of Sciences (IO PAN)
www.iopan.gda.pl

Ministry of Climate
www.gov.pl/web/climate

Ministry of Science and Higher Education
www.gov.pl/web/science

Poznań University of Life Sciences (PULS)
puls.edu.pl/en/

University of Science and Technology (AGH)
www.agh.edu.pl/en

Table 26. The future ICOS Poland stations network

MAP NUMBER	STATION NAME	STATION ABBREVIATION	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
1	ATM East	*	Atmosphere	Tall tower	Class 1	University of Science and Technology
2	ATM West	*	Atmosphere	Tall tower	Class 2	University of Science and Technology
3	Białystok	BIK	Atmosphere	Tall tower	Class 2	Institute of Environment Protection
4	Chmiel	*	Ecosystem	Agriculture	Class 2	Institute of Agrophysics of the Polish Academy of Sciences
5	Kraków	*	Ecosystem	City	Class 2	University of Science and Technology
6	Mężyk	*	Ecosystem	Forest	Class 2	Poznań University of Life Sciences
7	Pomerania	*	Ocean	Ship	Class 2	Institute of Oceanology of the Polish Academy of Sciences
8	Rzecin	*	Ecosystem	Wetland	Class 1	Poznań University of Life Sciences

* To be determined later

ICOS Romania

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Brăila Islands LTSER: an Ecosystem station of future ICOS Romania

The role of ICOS Romania

The main goal of the ICOS Romania is to contribute to the understanding of the carbon cycle dynamics, particularly the greenhouse gases, in some of the important ecosystems around the country. The ICOS Romania network contributes to identifying and quantifying the effects of the land use, climate variability, biodiversity and socio-economic activities on the carbon cycle.

ICOS Romania infrastructure

ICOS Romania will consist in the beginning of five Ecosystem stations. These stations will cover three typical land uses that are important in the region: wetlands, agricultural land and grassland. The stations located at the Danube Delta and the Great Brăila Island are particularly important in studying the long-term role of wetlands in carbon storage as well as in understanding the involved short-term mechanisms and the relationship between the carbon storage and the land use change. Studying this is especially important, since human activities result in a dramatic decrease of wetland surfaces.

The Ecosystem stations of the Brăila Islands LTSER and the LTSER Neajlov Catchment will focus on studying the carbon dynamics in agricultural systems, since agriculture is considered highly important in the southern part of Romania. The future Ecosystem station, Neajlov Catchment LTSER, will be developed during 2022 to focus on observing the grassland ecosystems. The station will be co-located with the Long-term Socio-Ecological Research (LTSER) Platform. In the near future, in 2025, two more Ecosystem stations are planned to be co-located with another European Research Infrastructure, the International Centre for Advanced Studies on River-Sea Systems (DANUBIUS-RI).

ICOS Romania is a distributed consortium that will be developed stepwise and maintained through the contribution of several stakeholders in

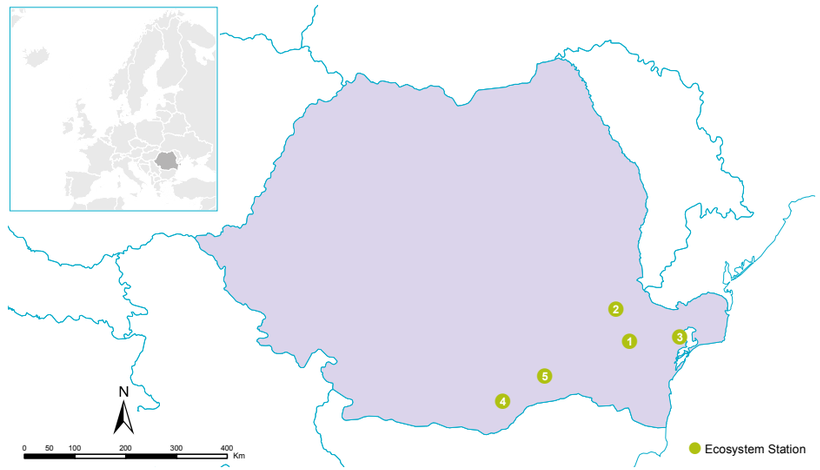

Figure 27. Future ICOS Romania station network. The numbers in the map correspond to the numbers in Table 27.

Romania: University of Bucharest, National Institute of Research and Development for Optoelectronics, National Meteorological Administration, National Institute for Research and Development on Marine Geology and Geo-Ecology, Brăila Agricultural Research and Development Station, and National Institute for Research and Development in Forestry "Marin Drăcea".

The ICOS Romania funding structure

The construction and running costs for the first years of the ICOS Romania are ensured by the University of Bucharest through an EU Structural Fund project “Strengthening the Capacity of Ecosystem Research and Biodiversity of the University of Bucharest by E-Science and Technology - LifeWatch Romania”, which is funded by the European Regional Development Fund through the Competitiveness Operational Programme. The project will allow Romania to co-locate stations of several research infrastructures, including ICOS, to study the Earth intensively. ICOS belongs to the updated Romanian National Roadmap of Research Infrastructures 2021.

Additional funding for the logistics of the ICOS stations will be obtained through projects financed by different ministries: Ministry of Environment, Waters and Forests; Ministry of Research, Innovation and Digitization; Ministry of Agriculture and Rural Development, and hopefully by private foundations.

A LIST OF ICOS ROMANIA PARTNERS AND FUNDERS

National Institute of R&D for Optoelectronics
www.inoe.ro/en

Research Centre in Systems Ecology and Sustainability / University of Bucharest
rcses.unibuc.ro

National Meteorological Administration
www.meteoromania.ro

Agricultural Research and Development Station Brăila
www.scdabraila.ro

Danube Delta National Institute for Research and Development
ddni.ro/wps

National Institute for R&D on Marine Geology and Geo-Ecology
geoecomar.ro/en

National Institute for Research and Development in Forestry "Marin Drăcea"
www.icas.ro

Ministry of Environment, Waters and Forests
www.mmediu.ro

Ministry of Research, Innovation and Digitization
www.research.gov.ro

Ministry of Agriculture and Rural Development
www.madr.ro/en

Table 27. The future ICOS Romania stations network

MAP NUMBER	STATION NAME	STATION ABBREVIATION	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
1	Brăila Islands LTSER wetland	*	Ecosystem	Mires	Class 1	Brăila Natural Park, University of Bucharest
2	Brăila Islands LTSER agriculture	*	Ecosystem	Cropland	Class 2	Agricultural Research and Development Station Brăila (Academy of Agricultural and Forestry Sciences “Gheorghe Ionescu Şişeşti”, Bucharest), University of Bucharest
3	Danube Delta Biosphere Reserve	*	Ecosystem	Mires	Class 1	Danube Delta National Institute for Research and Development, University of Bucharest
3	LTSER Neajlov Catchment	*	Ecosystem	Cropland	Class 2	Comana Natural Park, University of Bucharest
4	Neajlov Catchment LTSER	*	Ecosystem	Grassland	Class 2	Comana Natural Park, University of Bucharest

* To be determined later

9 APPENDICES

Terms and definitions

TERMS	DEFINITIONS
Carbon Portal	The combined real and virtual data centre in which ICOS observational and elaborated data products and associated metadata are stored, archived, accessed and curated.
Copernicus	Copernicus is the EU's Earth observation programme offering information services based on satellite, in situ and modelling.
Data Policy	This document is an internal rule that sets out the principles for the handling of and access to data and e-science tools within the ICOS Research Infrastructure as well as the rights and obligations of data providers and users.
EUDAT (European Data Infrastructure)	EUDAT's vision is that data are shared and preserved across borders and disciplines by enabling data stewardship within and between European research communities through a Collaborative Data Infrastructure (CDI), a common model and service infrastructure for managing data that spans all European research data centres and community data repositories.
FLUXNET	FLUXNET is a global network of micrometeorological tower sites that use eddy covariance methods to measure the exchanges of carbon dioxide, water vapour and energy between terrestrial ecosystems and the atmosphere.
Head Office	(REWRITE)The Operational Unit in which work the administrative staff in charge of supporting the Director General in ICOS ERIC's day-to-day management and that is mainly located on the premises of the statutory seat but may also have components in other countries.
Host Contribution	The financial support of Members or Observers hosting an ICOS Central Facility.
Host Premium Contribution	The financial support of Members or Observers hosting an ICOS Head Office and Carbon Portal.
ICOS Research Infrastructure (ICOS RI)	The distributed research infrastructure that is coordinated by ICOS ERIC and involves Central Facilities and ICOS NNs.

TERMS	DEFINITIONS
ICOS Central Facilities (CFs)	The centres analysing samples and/or processing data obtained from ICOS NNs, supporting and supervising them and performing technological surveillance on sensors and methods.
ICOS National Networks	ICOS ERIC Member countries' Atmosphere, Ecosystem and Ocean networks of stations.
ICOS Research Infrastructure Committee (ICOS RICOM)	The advisory body for the Director General of ICOS ERIC in all general matters to ensure the consistency, coherence and stability of the Research Infrastructure; it includes one representative from the Head Office, Carbon Portal, each ICOS Central Facility and each Monitoring Station Assembly.
ICOS Station	An observatory in an ICOS NN that has been labelled by ICOS ERIC and follows the standardised measurement protocols and quality-assurance and data-management plans defined in ICOS' internal technical and scientific documents. An ICOS station may be labelled for atmospheric, ecosystem or oceanic research purposes. There are both Class 1 and Class 2 stations, which are defined in the Scientific and Technical Description.
ICOS Class 1 Station	(For Ecosystem and Atmosphere stations.) Has complete equipment for measuring the full set of ICOS core parameters.
ICOS Class 2 Station	(For Ecosystem and Atmosphere stations.) Has the same analytical precision as a Class 1 station but measures fewer physical parameters than a Class 1 station.
ICOS Associated Station	(For Ecosystem stations). Measures a selection of parameters and has fewer obligations towards data submission and standards than Class 1 and Class 2 stations.
Internal Financial Rules	The document setting out the general financial principles of ICOS ERIC and the ICOS RI, in particular rules regarding the day-to-day management of financial matters, financial contributions to ICOS ERIC and financial reporting.
Monitoring Station Assembly (MSA)	An assembly of scientific and technical experts from the ICOS NNs; there is one MSA for each thematic area (Atmosphere, Ecosystem and Ocean).

Abbreviations

ABBREVIATION	FULL NAME
^{14}C	Radiocarbon
$^{14}CO_2$	Carbon dioxide containing a heavy isotope of carbon
ACTRIS	Aerosol, Clouds and Trace Gases Research Infrastructure
ATC	ICOS Atmosphere Thematic Centre
CAL	ICOS Central Analytical Laboratories
CAMS	Copernicus Atmosphere Monitoring Service
CFs	ICOS Central Facilities, i.e., ATC, ETC, OTC, CAL
CH_4	Methane
CMCC	Euro-Mediterranean Centre on Climate Change
CO	Carbon monoxide
COP	The informal name for the Conference of the Parties to the United Nations' Framework Convention on Climate Change (UNFCCC)
CO_2	Carbon dioxide
CRL	Central Radiocarbon Laboratory of CAL
DG	Director General of the ICOS RI
DOI	Digital Object Identifier
EAB	ICOS Ethical Advisory Board
EGU	The European Geosciences Union
eLTER RI	Integrated European Long-Term Ecosystem, critical zone and socio-ecological Research Infrastructure
ENVRI	European Environmental Research Infrastructures
ERIC	European Research Infrastructure Consortium
ESFRI	European Strategy Forum on Research Infrastructures

ABBREVIATION	FULL NAME
ETC	ICOS Ecosystem Thematic Centre
EU	European Union
EUDAT	European Data Infrastructure
FAIR	FAIR principles: Findable, Accessible, Interoperable, Reusable
FCL	Flask and Calibration Laboratory of CAL
FOS	Fixed Ocean Stations
GA	ICOS General Assembly
GAW	Global Atmosphere Watch programme (WMO programme)
GCOS	Global Climate Observing System
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GHGs	Greenhouse gases
GLODAP	The Global Ocean Data Analysis Project
GTOS	Global Terrestrial Observing System
GNI	Gross National Income
ICOS	Integrated Carbon Observation System
ICOS RI	ICOS Research Infrastructure
ICOS RICOM	ICOS Research Infrastructure Committee
IG3IS	Integrated Global Greenhouse Gas Information System
INRAE	French National Research Institute for Agriculture, Food and Environment
IPCC	Intergovernmental Panel on Climate Change
IW	Internal Working data

Abbreviations

ABBREVIATION	FULL NAME
MFT	Marine Flux Towers
MSAs	Monitoring Station Assemblies for ICOS ERIC Member countries' Atmosphere station, Ecosystem station and Ocean station networks
N_2O	Nitrous oxide
NN	ICOS National Network
NOAA	National Oceanic and Atmospheric Administration
NRT	Near-real-time
OTC	ICOS Ocean Thematic Centre
pCO_2	Partial pressure of carbon dioxide in the ocean
PI	Principal Investigator of measurement station(s)
PPFD	Photosynthetic Photon Flux Density
RI	Research Infrastructure
SAB	Scientific Advisory Board
SBSTA	Subsidiary Body for Scientific and Technical Advice
SF_6	Sulphur hexafluoride
SOCAT	Surface Ocean CO_2 Atlas
SOOP	Ship of Opportunity
TCs	Thematic Centres for Atmosphere, Ecosystem and Ocean observations (ATC, ETC and OTC)
UNFCCC	United Nations' Framework Convention on Climate Change
WMO	World Meteorological Organisation

The most significant EU projects of ICOS ERIC in 2022

PROJECT ACRONYM	DEFINITION/ABBREVIATION
ATMO-ACCESS	The EU Horizon 2020 project "Solutions for Sustainable Access to Atmospheric Research Facilities" (ATMO-ACCESS) is the organised response of distributed atmospheric research facilities for developing a pilot for a new model of Integrating Activities.
CoCO2	Copernicus evolution – Research activities in support of a European operational monitoring support capacity for fossil fuel CO_2 emissions (CoCO2) continues the work of the CO_2 Human Emissions (CHE) project. This EU Horizon 2020 project will sustain the development of a European capacity for monitoring anthropogenic CO_2 emissions.
ENVRI-FAIR	ENVRI-FAIR is an EU Horizon 2020 project. Its overarching goal is to implement the FAIR (Findable, Accessible, Interoperable, Reusable) principles in the ENVRI (Environmental Research Infrastructures) community and to connect it to the European Open Science Cloud (EOSC). The final goal is to provide an open-access platform for interdisciplinary environmental research data in the European Research Area utilising the EOSC.
EOSC	The European Open Science Cloud is envisioned by the European Commission as a supporting landscape to foster open science and open innovation: a network of organisations and infrastructures from various countries and communities that supports the open creation and dissemination of knowledge and scientific data.
e-shape	E-shape is an initiative that brings together decades of public investment in Earth Observation and in cloud capabilities into services for the decision-makers, citizens, industry and researchers.
ICOS Cities	ICOS Cities (PAUL – Pilot Applications in Urban Landscapes) is an EU Horizon 2020 project that aims to develop a systematic greenhouse gas measurement system for urban areas.
RItrainPlus	The Research Infrastructure Training Plus (RItrainPlus) is an EU Horizon 2020 project which will design and deliver a training programme to fulfil the competency requirements for the current and future managers of European Research Infrastructures and Core Facilities.

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Situation in 1.3.2022

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Situation in 1.3.2022

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Greenhouse gases in the atmosphere are increasing constantly, thereby heating up our planet. To predict climate change and mitigate its consequences, it is important to observe greenhouse gases and their circulation between air, land and sea.

ICOS (Integrated Carbon Observation System) is a European research infrastructure producing standardised high-quality greenhouse gas data in 14 countries. Our data is free and open to all users.

The ICOS Handbook helps to understand how we operate. How is ICOS organised, what and how do we measure and what is the role of the Thematic Centres and National Networks? The Handbook also describes the technical specifications of stations and the process of becoming a Member.

This handbook aims to give a comprehensive overview of ICOS both for the people already within our community as well as for the countries considering membership. We also hope that anyone who is interested in ICOS will find this handbook useful.

www.icos-ri.eu

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