ICOS Handbook

Knowledge through observations

ICOS
INTEGRATED CARBON OBSERVATION SYSTEM

ICOS HANDBOOK TABLE OF CONTENTS

Foreword

Greenhouse gases are transported in the atmosphere with the winds. They can travel even thousands of kilometres. These gases may impact climate far away from the regions of their origin. In order to understand the gases, their sources, transport, sinks, and finally their balance, it is essential to have standardised in situ observations with broad geographical coverage. The Integrated Carbon Observation System, ICOS, provides this observational network throughout Europe, facilitating science and enabling better knowledge for decisions on climate change mitigation and adaptation.

ICOS is a research infrastructure that 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 when facing difficulties.

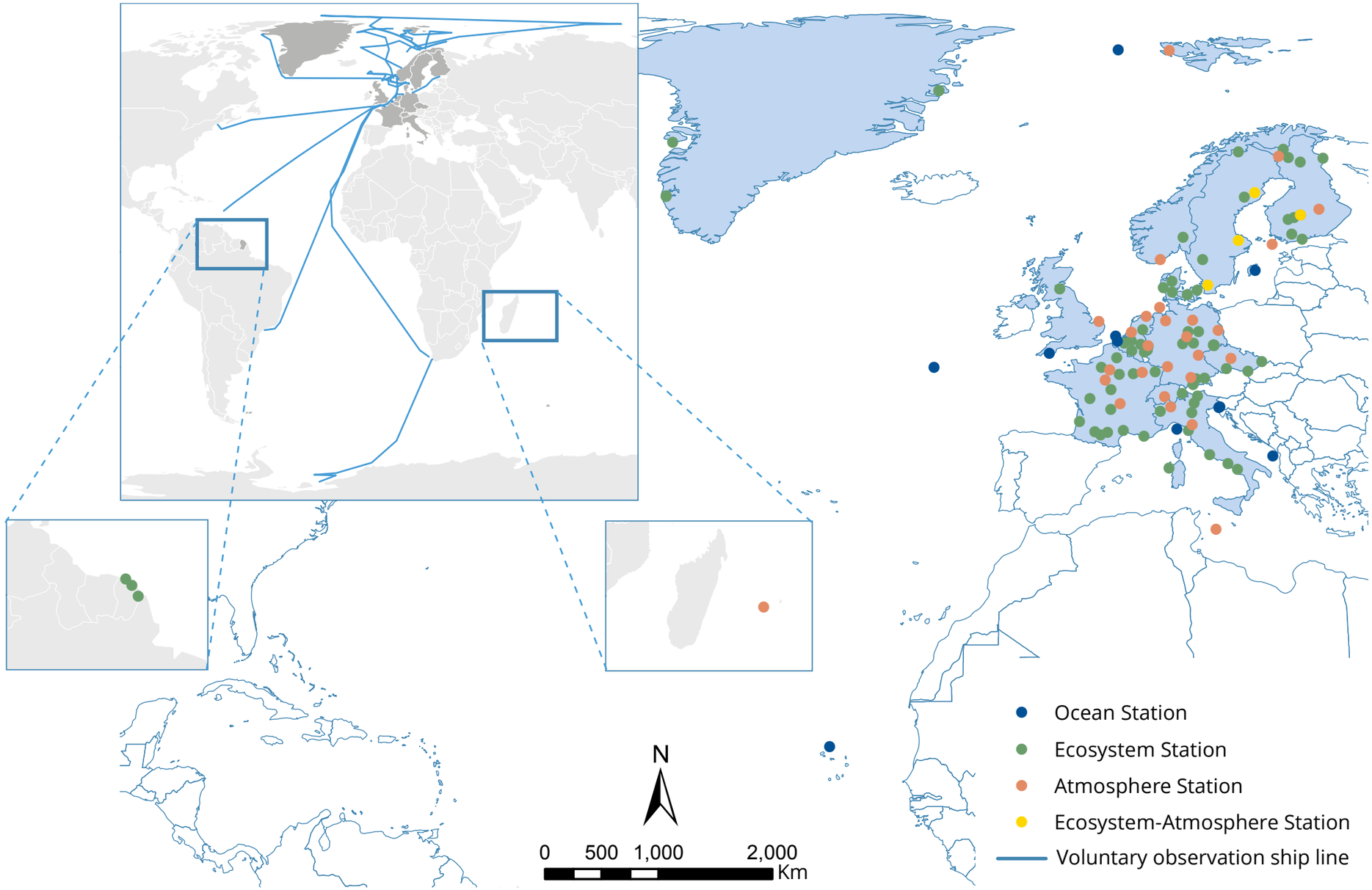
I suppose that it has been this unique combination of scientific excellence, technical competence and strong commitment to the Grand Challenge of climate mitigation that has convinced the European Strategic Forum on Research Infrastructure (ESFRI), the European Commission and many national ministries to support ICOS during the journey: from the first ESFRI roadmap in 2006 to an ERIC, and an operational Landmark Infrastructure today. Building a greater ICOS community together, for example, with scientists, technicians and our stakeholders, has been the base of our success. We are proud and grateful for this achievement.

This book gives a comprehensive overview of ICOS research infrastructure, for example, of its data processing and data life cycle, organisational structure and technical details about station requirements. It also describes the impacts of ICOS and the process for a country to participate in this research infrastructure.

This is the second edition of the ICOS Handbook, published in 2019. 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



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

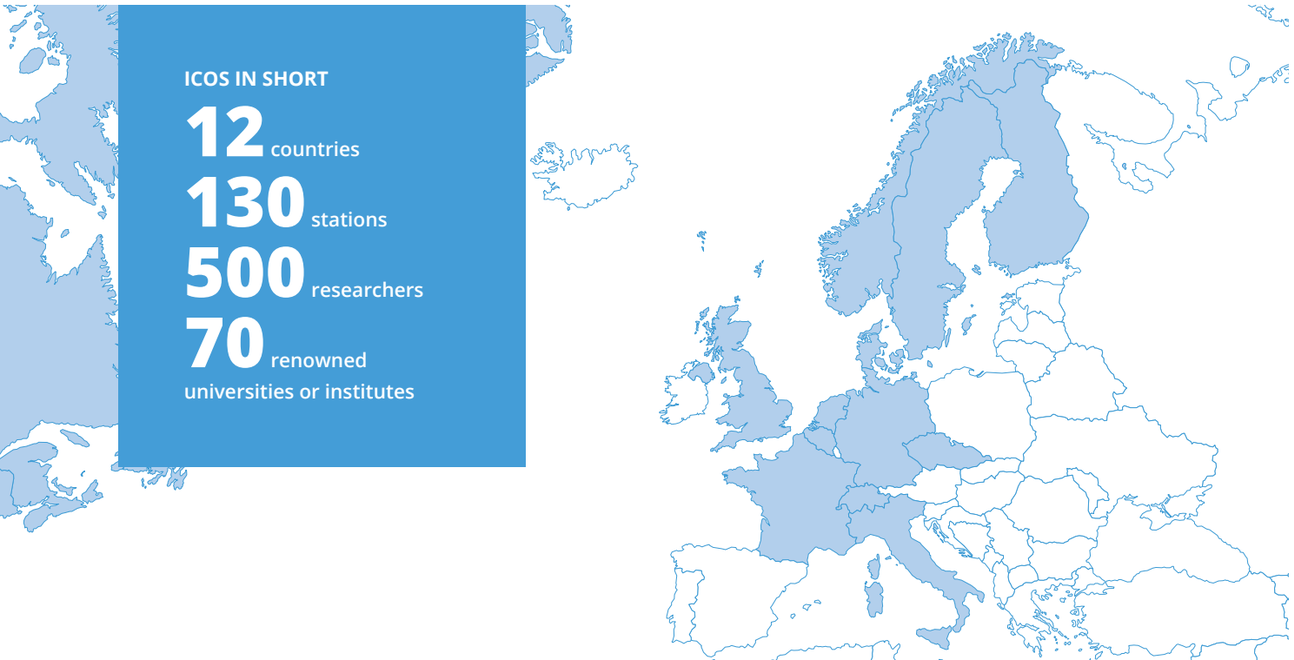
1 **ICOS is well connected to European and global networks.**

2 **We strengthen the scientific community by organizing events and bringing people together.**

3 **We promote the standardisation and curation of data.**

4 **Our community guides and trains its members and exchanges knowledge.**

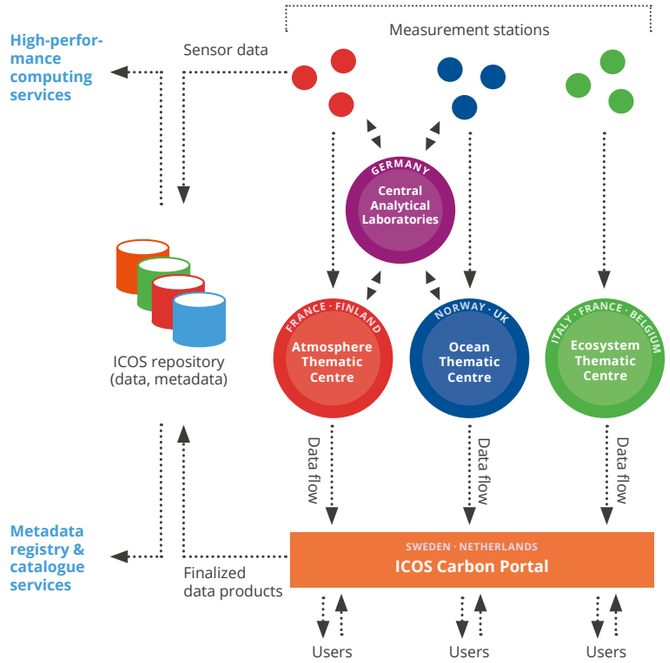
5 **ICOS supports its members in applying for multi-disciplinary consortium projects, hence they get more funding opportunities.**



ICOS IN SHORT

12 countries
130 stations
500 researchers
70 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-cp.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 whole labelling process might take anything up to a year.

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, 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 from more than 130 measurement stations across 12 European countries. The stations observe greenhouse gas concentrations in the atmosphere as well as carbon fluxes between the atmosphere, the land surface and the 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 the science-based knowledge that 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 current Member and Observer countries and beyond. More than 70 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 is recognized by the Subsidiary Body for Scientific and Technical Advice (SBSTA) of the United Nations Framework Convention on Climate Change (UNFCCC).

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 Global Atmosphere Watch programme of the WMO.

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) roadmap. The ESFRI roadmap identifies 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 foster scientific excellence cost-efficiently. ICOS has been established to ensure high-quality measurements of greenhouse gas concentrations 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 harmonized 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.

All 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 address the current pressing climate-change-related challenges by organizing science events that include, for example, a biennial ICOS Science Conference. Recently, 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 that are being analysed. These analyses will be discussed openly among the wider science community at a special session, 'The 2018 European Drought', which ICOS organised at the European Geosciences Union General Assembly in April 2019. After open discussion, the results will be written into manuscripts and submitted to peer-reviewed, high-impact journals for publication.

Promoting 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-upon 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

ICOS' Central Facilities (CFs) and Carbon Portal provide trainings, for example for stations' Principal Investigators, managers and technicians on any issues necessary. 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 scientific and technical prerequisites and developments. For example, ICOS partners have been very successful in getting funded by EU Horizon 2020 projects. All ongoing ICOS projects are listed in 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 WMO. 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 organizations, such as the SBSTA of the UNFCCC.

Technology and innovation

ICOS' effectiveness in unifying the European climate science field has already had effects on technology and innovation. The bigger the ICOS network is, the bigger its impact 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 standardized, 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 standardized, 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 utilized 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 more than 130 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 11 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 standardization of data archiving, data formats and processing methods. The Central Facilities are hosted by universities or research institutions in the Member countries.

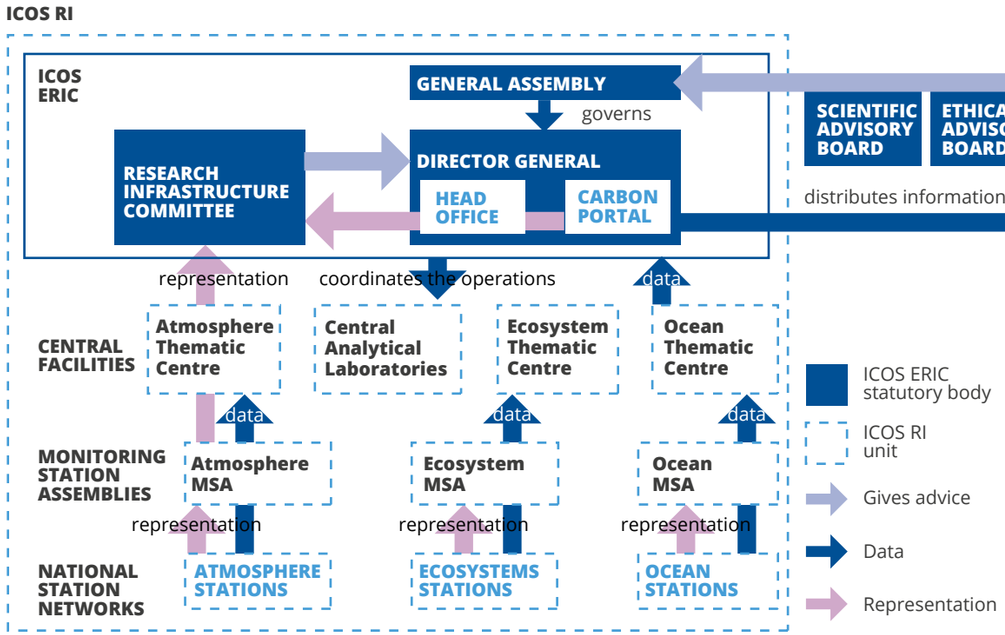
ICOS operations are coordinated by ICOS ERIC, which is a specific legal entity for European RIs created by the European Commission. ICOS ERIC consists of the Head Office, coordinating the RI operations, and the Carbon Portal, collecting and distributing ICOS data and derived products. In addition to 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 at overall science plans and directions, and to analyse the scientific results and impact of the ICOS RI. 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 funding from their member countries to ensure their operations. Additionally, new developments and innovations are supported through external funding, for example, by the European Commission's Framework Programmes for Research and Innovation.

ICOS has three levels of funding, mirroring the basic organisational structure of a distributed RI. ICOS ERIC receives membership contributions from the participating countries as well as host premium contributions from Finland, Sweden, the Netherlands and France. Central Facilities receive host contributions from their countries or in-kind contributions from their host institutions (70–80% of their total funding) and station contributions through ICOS ERIC. National Networks receive funding from their governments or in-kind contributions from their host institutions.

Calculating Member and Observer contributions

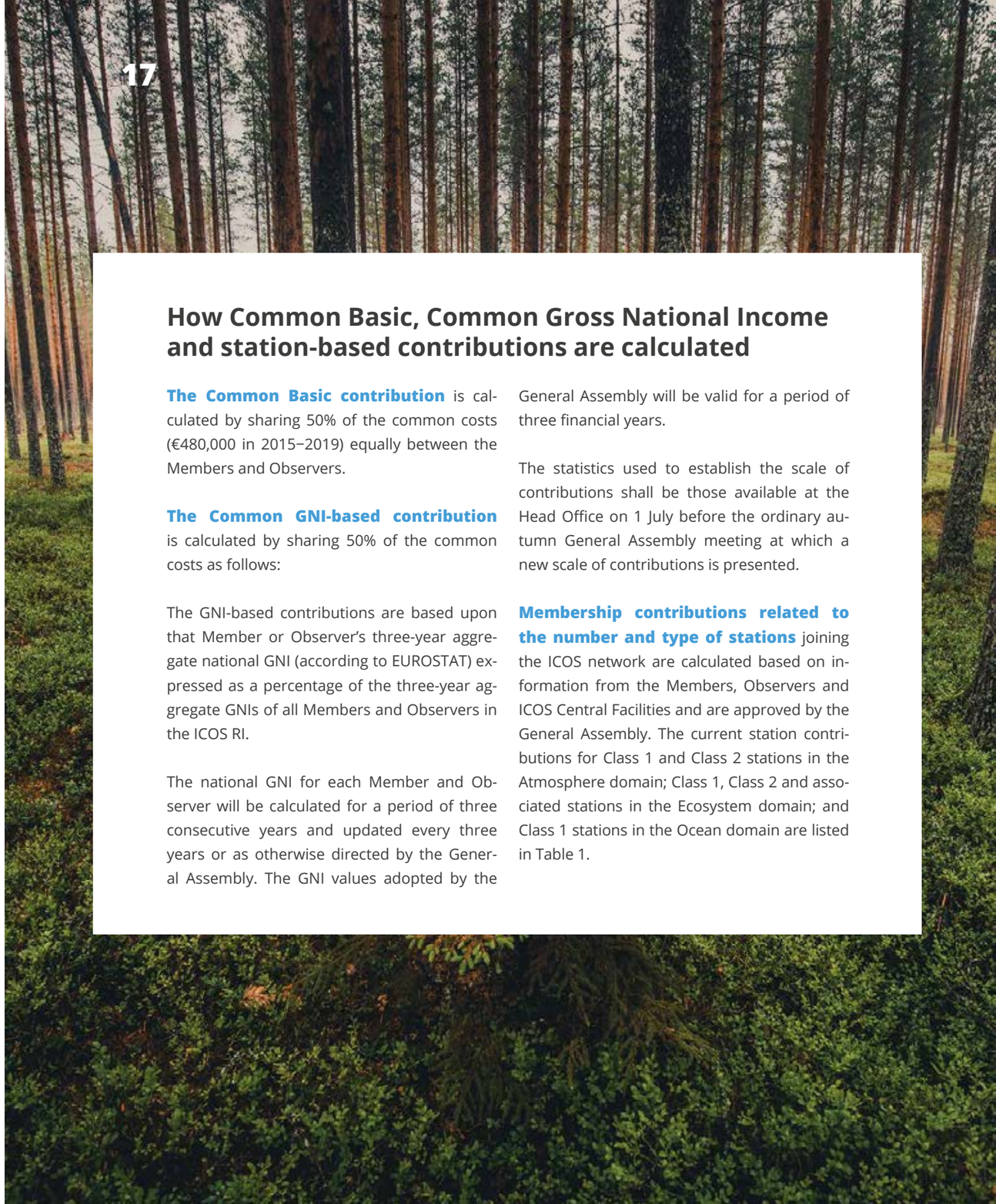
Annual membership contributions to ICOS ERIC, as well as host premium contributions by the hosting countries, cover activities that are of general benefit to the whole ICOS RI community: users, Members and Observers. ICOS ERIC statutes and the Internal Financial Rules of the ICOS RI set the principles 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 first five years of operations. The budget will depend, for example, on the number of Members and will be 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).

For the next five years (2020–2024), ICOS ERIC is expecting no major changes in the Host premium contributions from Finland and France. The Carbon Portal is covered by the Host premium contribution



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

The Common Basic contribution is calculated by sharing 50% of the common costs (€480,000 in 2015–2019) equally between the Members and Observers.

The Common GNI-based contribution is calculated by sharing 50% of the common costs as follows:

The GNI-based contributions are based upon that Member or Observer's three-year aggregate national GNI (according to EUROSTAT) expressed as a percentage of the three-year aggregate GNIs of all Members and Observers in the ICOS RI.

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

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 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.

from Sweden, and the contribution has always been negotiated between the Carbon Portal and the Swedish funding organisation.

Changes in the Common basic and Station-based contributions will be implemented after the decision is made by the General Assembly. The membership contribution to the Central Facilities should strengthen the financial sustainability for the whole ICOS RI. 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.

STATION TYPE	ANNUAL STATION CONTRIBUTION, €
Atmosphere Class 1	31,150
Atmosphere Class 2	11,400
Ecosystem Class 1	6,000
Ecosystem Class 2	3,000
Ecosystem associated	1,500
Ocean Class 1	7,750

Table 2. ICOS ERIC revenue and expenditure structure for 2016–2018, the 2019 numbers are an estimate.

REVENUE	2016*	2017	2018	2019e
Common basic contribution	213,863	218,663	218,663	218,663
Common GNI based contribution	205,714	205,714	205,714	205,714
Station based contribution to the Central Facilities	1,037,051	1,032,251	1,105,451	1,105,451
Host premium contribution (Head Office)	1,225,571	938,471	783,786	950,000
Host premium contribution (Carbon Portal)	783,089	676,847	689,611	767,831
Other ICOS ERIC (incl. projects, science conference)	148,856	534,610	1,144,797	913,664
TOTAL	**3,614,144**	**3,606,556**	**4,148,022**	**4,161,323**
EXPENDITURE	**2016***	**2017**	**2018**	**2019e**
Head Office activities (incl. projects, science conference)	993,583	1,209,955	1,960,839	1,915,019
Carbon Portal activities (incl. projects, etc.)	1,079,142	1,052,676	1,188,096	1,508,452
Central Facilities (CFs) activities	1,037,051	1,032,251	1,105,451	1,105,451
TOTAL	**3,109,776**	**3,294,882**	**4,254,386**	**4,528,922**
RESULT	**504,368.03**	**311,674.54**	**-106,364.30**	**-367,599.00**

*The 2016 figures presented here differ from the GA-approved figures for that year. The reporting template was changed after 2016, and transitions from the previous year in terms of revenues or expenses are no longer included in the reports. For comparability, the 2016 figures have been adjusted to match the new template.

2 ICOS STATION LABELLING PROCESS: A quality assurance

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 organized 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 harmonized data processing, quality control and archiving are guaranteed through the Thematic Centres and the Carbon Portal data services to will ensure the highest quality, comparability and credibility for the data.
- The provision of elaborated data products, such as advanced visualizations 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.

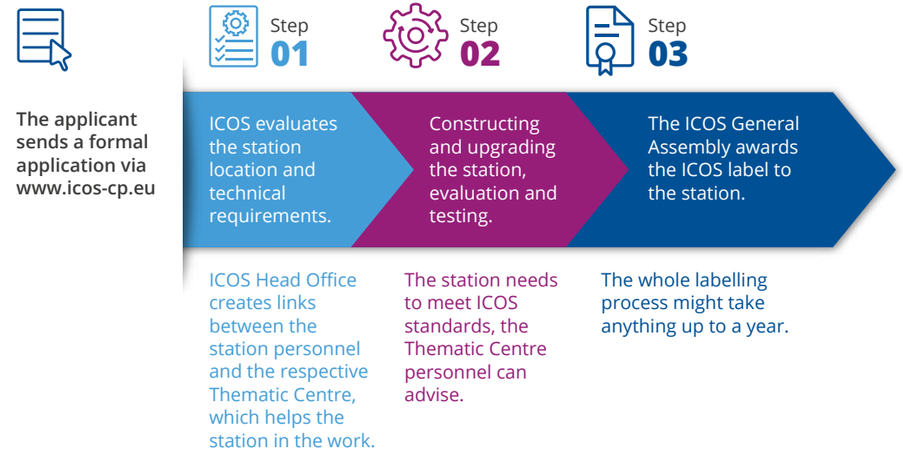
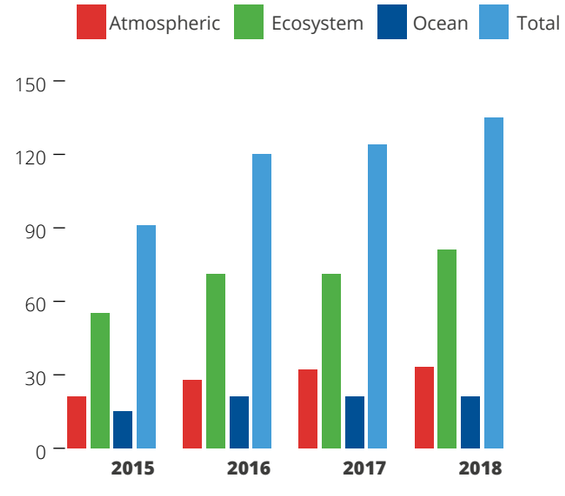


Figure 3. Number of ICOS stations in 2015–2018. The total number of stations was 134 at the end of 2018.



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 more than 130 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 the beginning of 2019, 36 stations had received an ICOS label, and the plans are that most of the current stations will be labelled by the end of 2020.

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 possible the machine-to-machine communication of data. Metadata and other descriptions are associated.

ICOS uses Creative Commons Attribution 4.0 International (CC4BY) 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 Digital Object Identifiers (DOIs) and Persistent Identifiers (PIDs). 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 creates a World Wide Web address (URL: Uniform Resource Locator) to a landing page where the metadata can be viewed or accessed by either humans or machines. 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

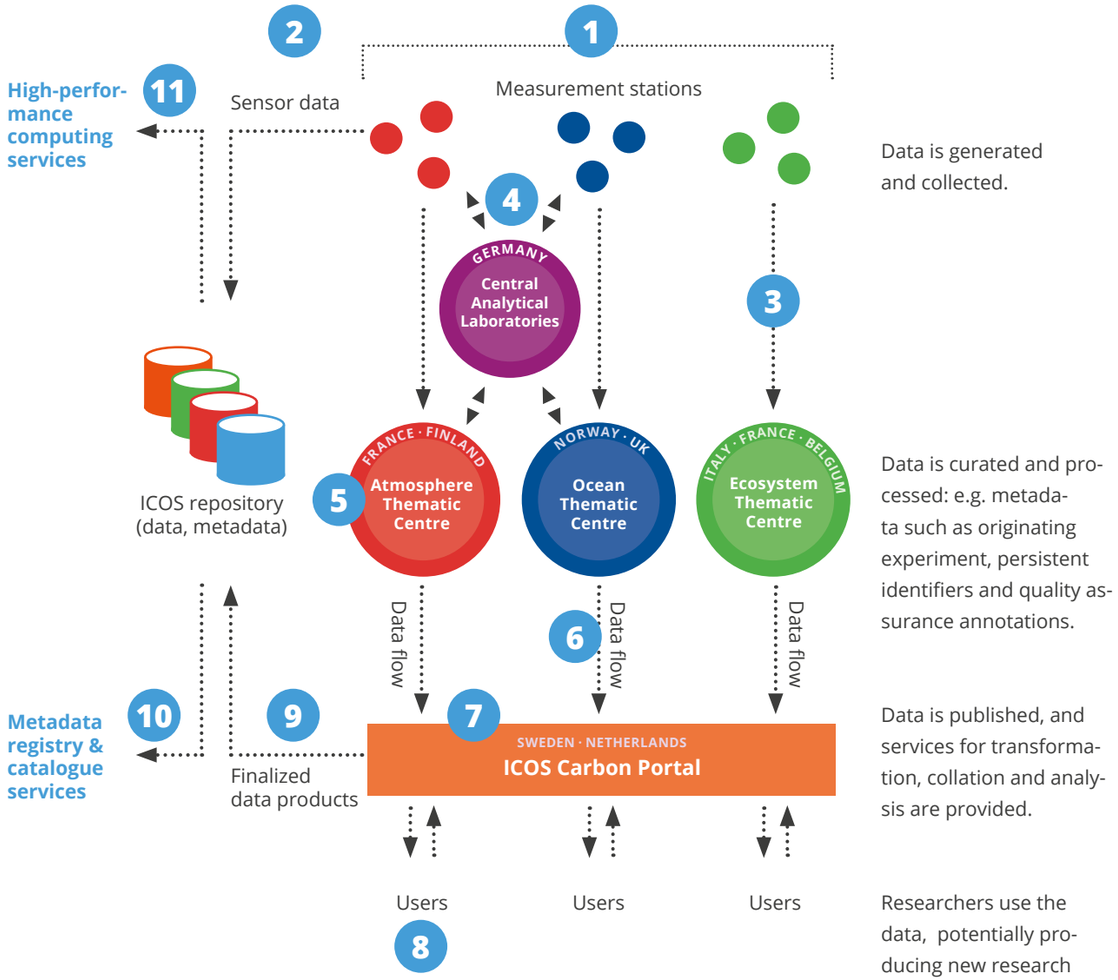
The following schematic diagram (Figure 4) shows the standardised ways of handling data within ICOS.

1. Data are collected at ICOS measurement stations. There are more than 130 sites in 12 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 re-measure. Therefore, copies of all '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.

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.

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



4. In addition to the three Thematic Centres, the Central Analytical Laboratories (CAL) is 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 standardized 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 finalized 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 organizing and taking care of all ICOS datasets. The Carbon Portal is the 'one-stop shop' for ICOS data products and offers advanced search, visualization 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 will also provide user-community 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).

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, 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.

4 TECHNICAL DESCRIPTION: The operations of ICOS research infrastructure

Raw data
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.

Level 0 data
Level 0 data are data in physical units either directly provided by instruments or converted from engineering units (for example, mV, mA, Ω) to physical units at the Thematic Centre. They may have been filtered by a quality check (for example, thresholds).

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. 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 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. The Level 1 data are used for internal quality checks, as in 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 upon, by collaborative projects.

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 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 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 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, SF_6), 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

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: weekly sampled 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

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		50	50	50
CO continuous in situ measurement			+ 20 (in addition to CO_2/CH_4 cost)	+ 20 (in addition to CO_2/CH_4 cost)
CO/N_2O continuous in situ measurement				110
Periodic air sampling for CO_2, CH_4, N_2O, SF_6, CO, H_2 and CO_2 isotopes	Flask sampler + 100 flasks with shipment cases		40 + 20	40 + 20
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		**85-140**	**215-310**	**395-490**

* 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).

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, 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.

Atmosphere Thematic Centre: Coordinating observations and processing data

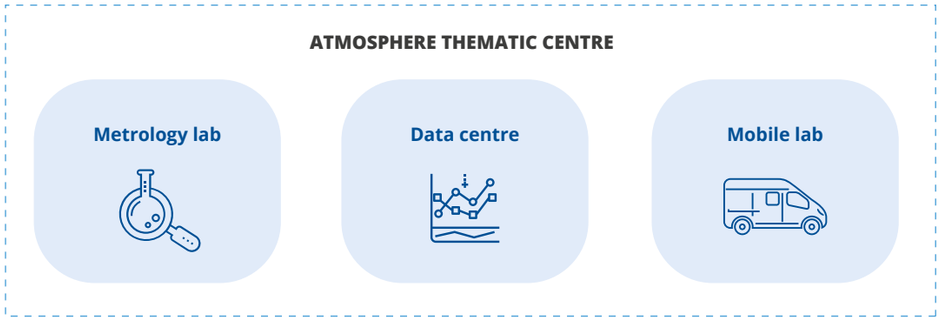
The ICOS Atmosphere observations are coordinated by the ATC in close cooperation with the Atmosphere Monitoring Station Assembly and Central Analytical Laboratories. The ATC is composed of a data centre and a metrology lab and is complemented by an in situ station quality-control mobile lab (Figure 5).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

Table 5. Estimated annual manpower requirement (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.



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.

By meeting these goals, the ATC will help organise the Atmosphere network for optimal long-term operations. In the ATC, harmonization in procedures and equipment with the appropriate Quality Assurance/Quality Control plan will greatly improve 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. It is the central labelling and training centre for ICOS atmospheric measurements, and it coordinates the development of atmospheric measurement protocols.

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 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 the unique 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 atmospheric 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 University of Heidelberg.

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, 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.

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
- Cavity ringdown spectrometer (Picarro G2301) for CO_2 and CH_4 measurements
- FTIR Spectrometer (Ecotech Spectronus FTIR) for CO_2, N_2O, CO and CH_4 analyses
- 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
- Off-Axis Integrated Cavity Output Spectroscopy spectrometer (Los Gatos) N_2O/CO analyser
- 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 stations • 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 re-calibration 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 via gas proportional counting • Extraction of CO_2 from flask samples with subsequent graphitization 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 Observation networks will also be supplied by the FCL and CRL with maintained sampling equipment (flasks and CO_2-free NaOH solution). Sample logistics and sampling information will be handled centrally in the CAL database. The CAL database system will document 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 jointly developed by the CRL and FCL. 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 will allow for measurement data to be re-processed at any time, selected, analysed and transferred to the ATC.

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).

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 standardized 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.

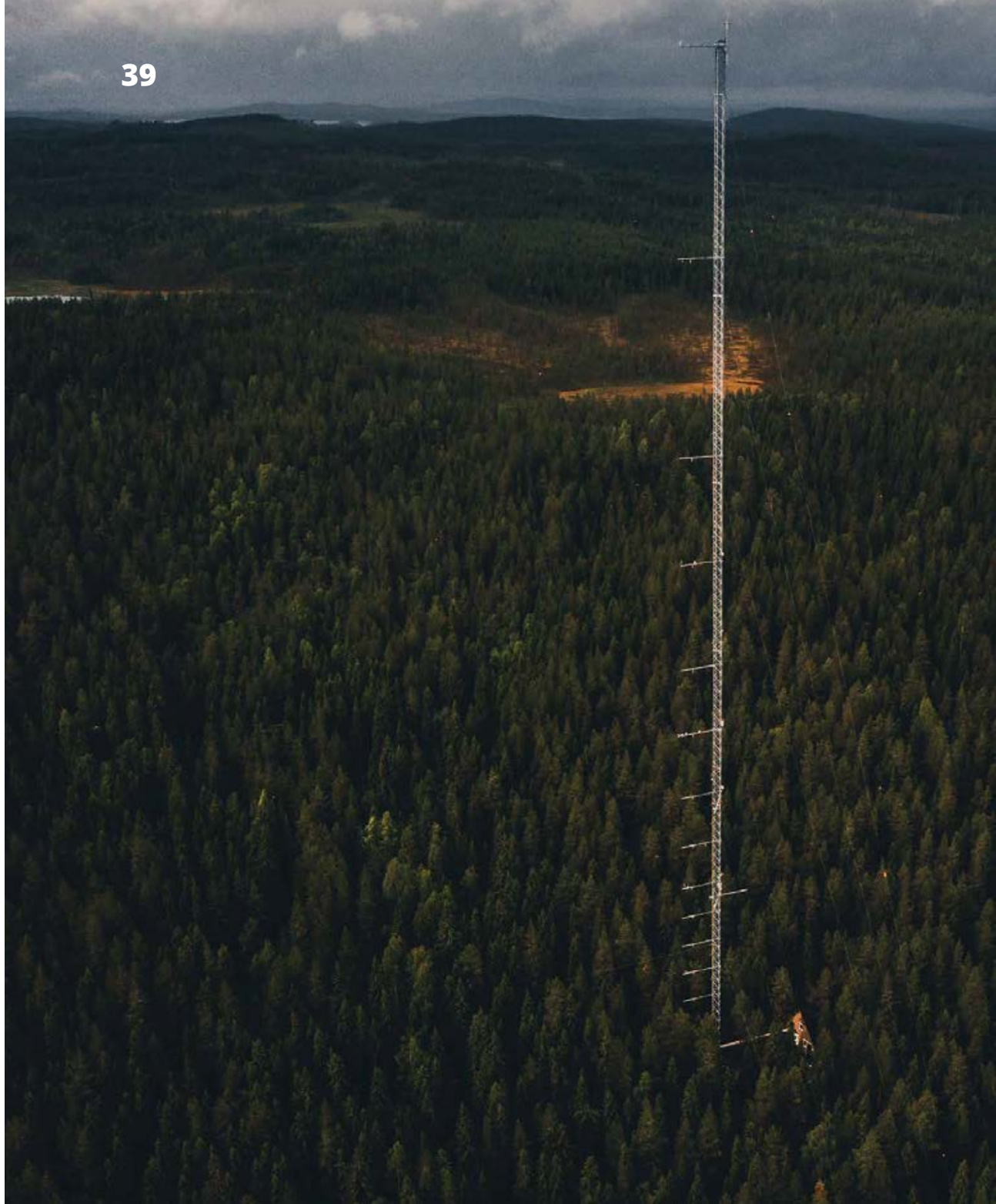


Table 7. List of variables that are collected at the various ICOS Ecosystem stations (Class 1 and Class 2) for the various ecosystem types.

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.

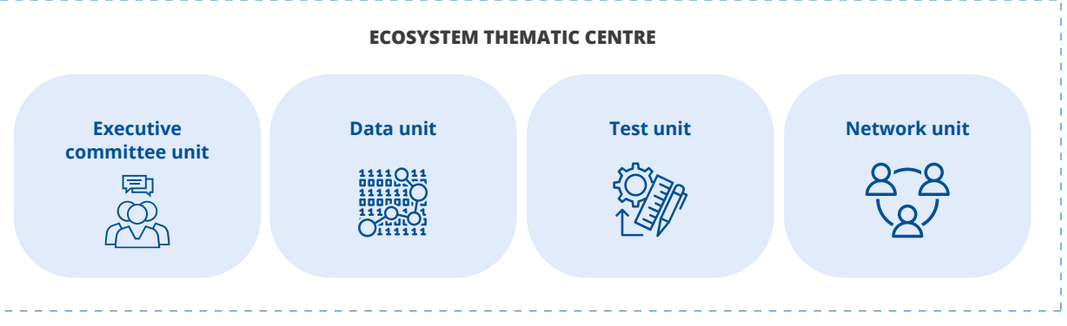
Table 8. Estimated equipment cost (k€) for the ICOS Ecosystem station

CATEGORIES	FOREST		CROP		GRASS		MIRE	
	Class 1	Class 2	Class 1	Class 2	Class 1	Class 2	Class 1	Class 2
Infrastructure	105.0	105.0	25.0	25.0	25.0	25.0	32.0	32.0
CO_2, H_2O energy EC	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0
Storage CO_2 and H_2O	27.0	27.0	0.0	0.0	0.0	0.0	0.0	0.0
CH_4 EC	50.0	0.0	50.0	0,0	50.0	0.0	50.0	0.0
N_2O EC	125.0	0.0	125.0	0.0	125.0	0.0	125.0	0.0
Storage CH_4	35.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Storage N_2O	35.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Radiations	10.0	7.5	10.0	7.5	10.0	7.5	10.0	7.5
Soil meteorology	21.0	14.0	21.0	14.0	21.0	14.0	21.0	14.0
Basic meteo	28.5	25.0	20.0	18.0	20.0	18.0	20.0	18.0
Precipitations	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Phenology-Camera	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Soil CO_2 automatic chambers	65.0	0.0	65.0	0.0	65.0	0.0	65.0	0.0
CH_4 and N_2O fluxes by automatic chambers								
Ancillary data	15.0	5.0	12.0	12.0	12.0	12.0	8.0	8.0
Tree diameter	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Leaf N content								
Soil carbon content								
Management, disturbances, C & N import and export information								
Site characterization								
Dataloggers, other costs, replacements	6.0	4.0	6.0	4.0	6.0	4.0	6.0	4.0
TOTAL	**573.0**	**233.5**	**380.0**	**126.5**	**380.0**	**126.5**	**383.0**	**129.5**

Table 9. Estimated annual manpower requirement (PM) and maintenance cost (k€) for the operation of an ICOS Ecosystem station

CATEGORIES	FOREST		CROP		GRASS		MIRE	
	Class 1	Class 2	Class 1	Class 2	Class 1	Class 2	Class 1	Class 2
Installation PM	5.5	4.5	3.5	2.5	3.5	2.5	3.5	2.5
Maintenance PM, including sampling and ancillary data	30.0	19.0	29.0	21.0	31.5	23.0	27.5	18.0
TOTAL (PM)	**35.5**	**23.5**	**32.5**	**23.5**	**35.0**	**25.5**	**31.0**	**20.5**
Maintenance costs (k€)	4.5	4.0	9.2	8.1	9.2	8.1	9.2	8.1

Figure 6. Structure of the ICOS Ecosystem Thematic Centre.



Ecosystem Thematic Centre: Coordinating observations and processing data

The ICOS National Networks measurements of greenhouse gas fluxes over the continental ecosystems are coordinated by the ETC. The ETC coordinates and supports the ICOS Ecosystem network through coordination and training activities. It provides technical assistance to ICOS Ecosystem sites and develops and tests new measurement methods and instruments. It also calculates, processes and performs quality control on ICOS Ecosystem data. The ETC develops new methods for data processing and manages the ETC database, web pages and tools.

The ETC is responsible for the on-line processing of data on net ecosystem fluxes and their components, carbon pools and other auxiliary data as well as for instrument development in cooperation with the wider community. Diverse processing hierarchies are used for the production of the various datasets, resulting in various data levels. Ancillary information about the sites (for example: metadata; vegetation and soil characteristics; disturbances; management) will be processed to ensure a high standardization between the various sites.

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 Centre of Excellence on Plant and Vegetation Ecology: PLECO) in Belgium and the National Institute for Agricultural Research (INRA) in Bordeaux, France.

Although the ETC has been organized to maximize the interchangeability of the members so as to increase its robustness and share its competencies as much as possible, the groups involved have distinct fields of expertise and main responsibilities. In particular, the Italian partners, UNITUS and CMCC, coordinate the ETC and the fluxes and meteorological data processing. The University of Antwerp is responsible for the ancillary data collection and treatment, while INRA Bordeaux will receive, analyse and store the soil and vegetation samples. The ETC is organized 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.

Unit 2: The Data Unit's main tasks include NRT data 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 methods. The unit is responsible for interactions with instrument manufacturers and research centres as well as for roving system management for site validation and parallel measurements.

Unit 4: The Network Unit's main tasks include providing assistance to the ICOS Ecosystem stations and evaluation of station performances. 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 21 Ocean stations in seven 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 Voluntary Observing Ships (VOS). 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 Voluntary Observation Ships (VOS) and Fixed Ocean Stations (FOS). The VOS 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 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 4–12 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.

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

VOS 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 Table 11). 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.

Table 11a. List of required variables measured at ICOS Carbon-VOS stations.

VARIABLE	FREQUENCY	ACCURACY	REQUIRED FOR CLASS
Sea surface fCO_2	Quasi-continuous	±2 µatm	2
Intake temperature (SST)	Continuous	±0.05 °C	2
Water vapour pressure	Continuous	±0.5 mbar	2
Equilibrator pressure	Continuous	±2.0 mbar	2
Equilibrator temperature	Continuous	±0.05 °C	2
Delta-T (Intake/Equilibrator temperature difference)	Continuous	< 1.5 °C (normal) < 3 °C (ice edge)	2
Sea surface salinity (SSS)	Continuous	± 0.1 psu	2
Alkalinity	**	10 µmol kg^{-1}	1*
Dissolved Inorganic Carbon	**	5 µmol kg^{-1}	1*
Dissolved oxygen	**	±2%	1

*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 11b. List of required variables measured at ICOS FOS stations.

VARIABLE	DESIRED FREQUENCY	ACCURACY	REQUIRED FOR CLASS
Sea surface pCO_2	3/day (coastal) 1/day (open ocean)	±10 µatm	2
Sea surface temperature	3/day (coastal) 1/day (open ocean)	±0.02 °C	2
Sea surface salinity	3/day (coastal) 1/day (open ocean)	±0.1 psu	2
Alkalinity	**	4 µmol kg^{-1}	2*
Dissolved Inorganic Carbon	**	2 µmol kg^{-1}	2*
Dissolved oxygen	3/day (coastal) 1/day (open ocean)	±2%	2
Dissolved nutrients	**	±1%	1

* At least one of these variables must be provided.
**Frequency of measurements will be discussed during evaluation of the station following the observation goals stated above.

The current Ocean station setup consists of eleven VOS and ten 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.

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.

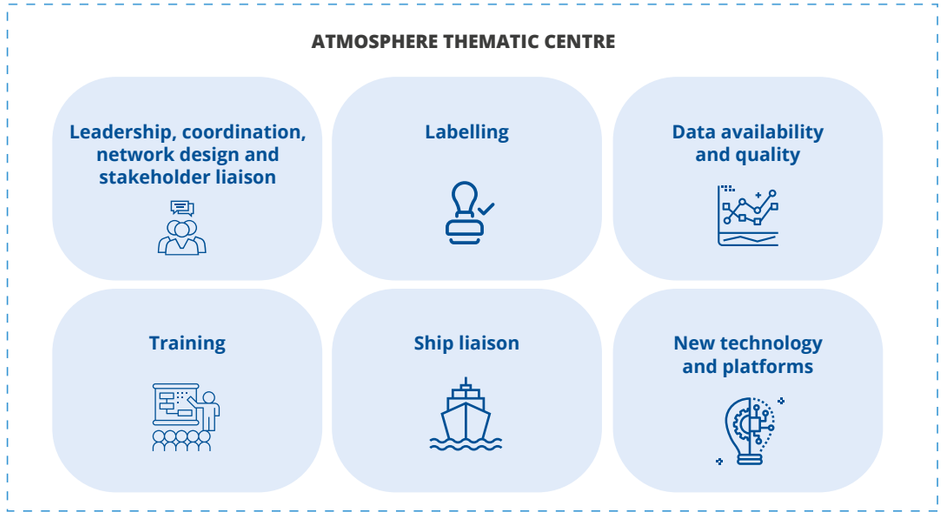


Figure 7. Structure of the ICOS Ocean Thematic Centre.

The Training Unit's task is to optimise and standardise performance of the network instrumentation and calibration. They provide guidance and technical support for new installations at individual stations.

The Ship Liaison Unit is in charge of the engagement with the shipping industry and coastal installations community, operating autonomous data collection systems focused on evaluating CO2 fluxes and other greenhouse gases across the air-sea interface. They also support the VOS community in sustaining stations and replacing stations.

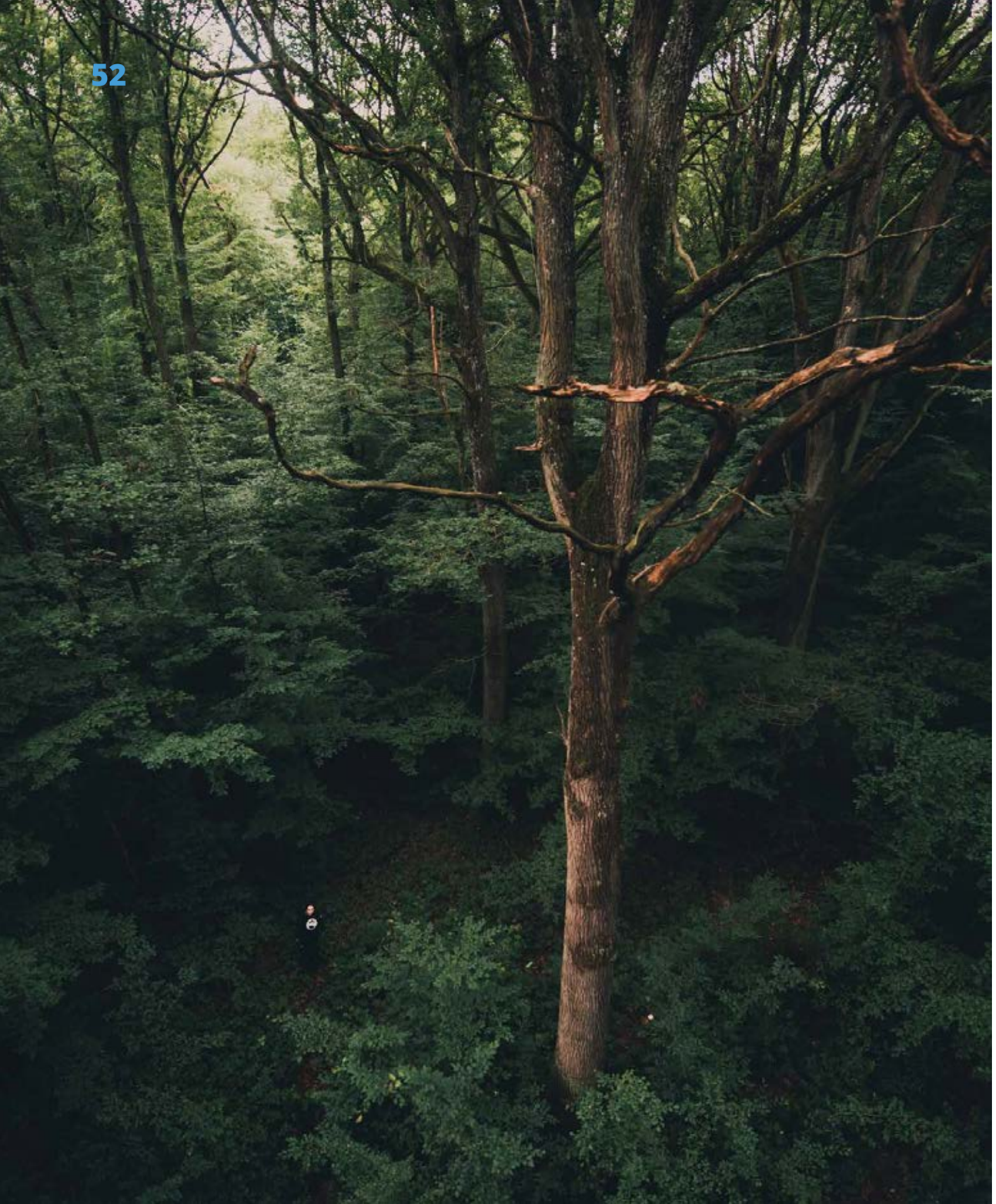
New Technology and Platforms Unit is in charge of new sensors and new platforms. Its task is to invite early adopters as collaborators or partners in future research grants to explore new technologies.

Table 12a. Estimated investment cost (k€) for an ICOS Ocean station.

CATEGORIES	DESCRIPTION	VOS		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	
Temperature, Salinity		20	20	10	10	
Dissolved Oxygen		10		5	5	
Nutrients				20		
Deployment platform	Buoy			80	80	
CO_2 flux measurements (incl. Tower, data aquisition)						60
Data acquisition, cost to visit the station				20	20	20
Total Alkalinity/Dissolved Inorganic Carbon (TA/DIC)		35				
Tubing, valve, pumps…		5	5			
Calibration		3	3			
Tanks, pressure regulators…		4	4			
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			
TOTAL		**197**	**152**	**170**	**150**	**80**

Table 12b. Estimated annual manpower requirement (PM) and maintenance cost (k€) for the operation of an ICOS Ocean station.

CATEGORIES	VOS		FOS		
	Class 1	Class 2	Class 1	Class 2	Flux tower
Maintenance (pCO_2, Sal, Temp) (PM)	9	9			
Maintenance DO (calibration included) (PM)	1.5		2		
Maintenance (TA/DIC) (PM)	1.5				
Maintenance CO_2 (PM)			3	3	4
Maintenance Temp, Sal (PM)			2	2	
Maintenance nutrients (calibration included) (PM)			2		
Sampling/analysis (PM)			4		
Station maintenance, data transmission, power etc. (PM)			3	3	2
Data validation (PM)					3
TOTAL (PM)	**12**	**9**	**16**	**8**	**9**
Maintenance CO_2 (k€)			5	5	5
Maintenance Temp, Sal (k€)			5	5	
Maintenance DO (calibration included) (k€)			3	3	
Maintenance nutrients (calibration included) (k€)			3		
Sampling/analysis (k€)			10	7	
Station maintenance, data transmission, power etc. (k€)			5	5	10
Consumables (pCO_2, Sal, Temp)	5	10			
Consumables DO (calibration included)	3				
Consumables (TA/DIC)	5				
TOTAL MAINTENANCE COSTS (K€)	**13**	**10**	**31**	**25**	**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 in the Carbon Portal are quality controlled through the ICOS Thematic Centres: the ATC, ETC, OTC and the CALs. The Carbon Portal will also have 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 standardized data-exchange protocols and techniques. Organizing 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, for example, 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 as well as the application of the standard of the INSPIRE directive. An agreement was made with other data centres on a metadata exchange format to facilitate exchange. Metadata used to be structured and updated at every Thematic Centre, but the Carbon Portal maintains its own metadata database according to the above-stated metadata standards.

Providing web services to 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, visualizing 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) could be 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 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 synthesizes 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, such as the comparison established by CarboScope (www.carboscope.eu) that is linked from the current ICOS website. Contributions will be 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.

Head Office

The ICOS ERIC Head Office supports the central aims of ICOS ERIC to coordinate, develop, monitor and integrate the activities of the ICOS RI by facilitating the work of the Director General, RI Committee, General Assembly, Central Facilities and National Networks. The Head Office supports the coordination of the infrastructure at the European level and coordinates and facilitates future network development and extension in cooperation with the ICOS Central Facilities and Monitoring Station Assemblies.

The Head Office works together with the Central Facilities to coordinate overall activities and develop the ICOS RI. The activities and deliverables of the Central Facilities are followed by the Head Office, and progress or possible problems and bottlenecks are discussed in the annual meetings with the Central Facilities as well as in telephone meetings when required. The Head Office supports the Central Facilities in finalising the first wave of the labelling of

the official ICOS stations and in signing the contracts with the labelled ICOS stations. Additionally, the Head Office supports the National Networks during the final steps of the labelling process in close discussion with the national Focal Points.

The administrative areas that are supervised and or dealt with at the Head Office include:

- Continuously acting as the General Secretariat for the General Assembly, Chair and Vice-Chair and providing support to the Financial Committee and Financial Committee Chair, the EAB and the Member and Observer delegates.
- Leading the human-resource management of the Head Office and the Carbon Portal's Director, including employment legal compliance.
- Implementing the financial management of the ICOS ERIC Head Office, including the processes of accounts payable, accounts receivable and invoice workflows.
- Planning and coordinating the financial management of the ICOS RI as specified in the Internal Financial Rules (budgeting, reporting, five-year planning).
- Supporting the procurement process is also one of the tasks, along with the management and supervision of service providers and office infrastructure, including IT.

The Head Office is also tasked with communications and outreach. Through its own actions and through supporting the National Networks and Central Facilities' communications, the Head Office's communications aim is by its leadership to increase the awareness and perceived value of ICOS and its data products among key external stakeholders and to increase the community's engagement with and sense of belonging towards ICOS. Furthermore, increasing general awareness of greenhouse gas measurement is within its scope. The Head Office utilises a wide pallet of means and actions to reach these goals, such as developing a unified ICOS brand; producing news, websites, social-media content and visual and printed materials; taking marketing actions; and participating in and producing events.

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

ICOS has multiple impacts. More accurate greenhouse gas information enables better science, provides important background information for decision-makers and helps to avoid costly mistakes.

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 only at long timescales. This makes measuring the impacts of ICOS challenging. To get a better grasp of them, ICOS carried out an Impact Assessment with an external consultancy (Technopolis Group) in 2018. The analysis mapped various impact pathways and provided ICOS with Key Performance Indicators (KPIs) as well as methods to measure them.

Although, in 2018, it was in many cases too early to review quantitative evidence of ICOS' impact, the study gathered baseline qualitative evidence of it. According to the report, ICOS is highly relevant within the European greenhouse gas research community. It has achieved this position largely through the successful implementation of measurement protocols throughout the RI and thanks to its ability to provide datasets of consistently high quality.

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.

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

The Technopolis impact-assessment team conducted a baseline bibliometric analysis of ICOS publications. At the time of the analysis, the DOI-minting process of ICOS was not yet widely in use, which, of course, significantly affects the results. However, they show that ICOS-originated papers (Figure 8) have the potential to be widely cited (Figure 9).

From the figures, 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 (108) of journals, of which the top 10 are depicted in Figure 10. While this is good for exposure, it prohibits effective measurement of ICOS' impact.

Many scientists who were interviewed for the Impact Assessment explained that the combination of ocean, atmosphere and ecosystem data and their measurement/analysis communities provides added value. 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 globally used OBSPACK, Carbontracker and Globalviewplus products, which 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. These are widely used, and the Central Analytical Laboratories are gaining importance in the global reference-sample network, being second to only the National Oceanic and Atmospheric Administration (NOAA), which has performed this role for decades.

Figure 8. ICOS-related publications, 2011–2018.

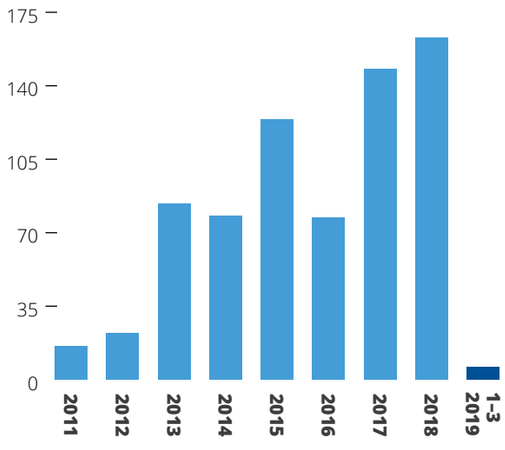
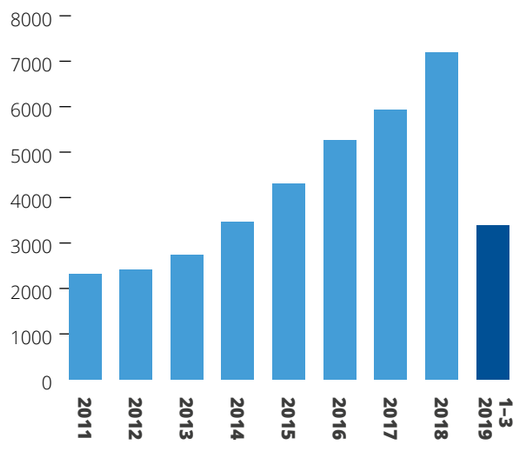


Figure 9. Citations of ICOS-related publications, 2011–2018.



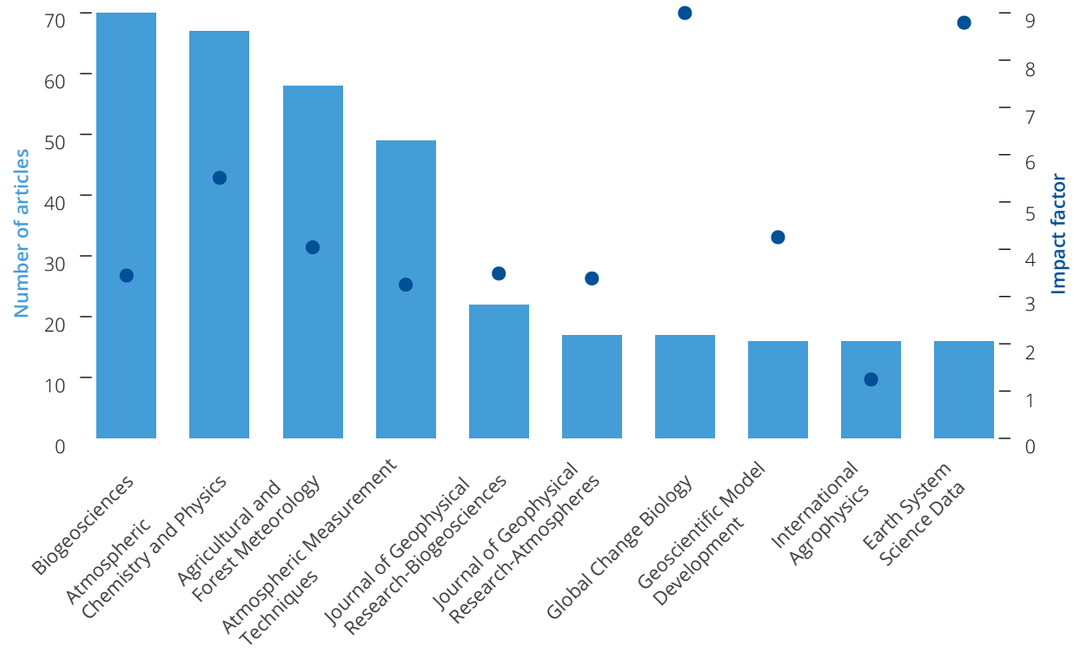
ICOS' socioeconomic impacts

Environmental RIs in general, and ICOS in particular, generate important knowledge on our ecological life-support systems, which provide priceless services. This is especially evident in the field of greenhouse gas management; if we do not reach our safe climate-change target level due to inadequate mitigation, climate change 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.

ICOS' task at the political level can best be described as the contribution of timely information relevant to greenhouse gas policy- and decision-making, supporting efforts towards the fulfilment of the resolutions of the Paris climate conference aimed at mitigating climate change. 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.

The United Nations Framework Convention on Climate Change (UNFCCC) has a well-established system for global climate observations (the Integrated Global Greenhouse Gas Information System: IG3IS) in which the commonly agreed-upon essential cli-

Figure 10. The top 10 journals in which ICOS articles have been published.



mate variables are defined by the Global Climate Observing System (GCOS). Greenhouse gas observations are an essential component of this system, and ICOS is a key European contributor to these observations. In the interviews conducted for the ICOS Impact Analysis, officials of the World Meteorological Organization (WMO) mention that the ICOS data and measurement standards are the best available in the world and that ICOS data are the core of global data inventories.

Not surprisingly, contacts with WMO are very active and at a high level, for example, between ICOS' Director General and the WMO's Secretary-General. Additionally, the ICOS Carbon Portal's Director chairs the scientific advisory group for greenhouse gases for the WMO Global Atmosphere Watch programme (GAW) and has also presented the ICOS data-processing and data-portal concepts within this framework. Additionally, the ICOS Carbon Portal's Director is a member of the executive steering group of the IG3IS initiated by the WMO. IG3IS uses atmospheric observations and inverse modelling to provide information on 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.

Furthermore, ICOS co-initiated the GEO Carbon and Greenhouse Gas Initiative (GEO-C) and hosts its secretariat. The GEO-C serves as an informal discussion forum for the major actors in the UNFCCC framework: IPCC, UNFCCC, the European Commission, the WMO, Copernicus, satellite observations via the Committee on Earth Observation Satellites (CEOS) and in situ components covered by ICOS. One of the short-term goals of the GEO-C is to map the organisations and their contributions to the requirements of the UNFCCC and to determine how these can support national climate-change mitigation. This leads to a roadmap of how scientific actors can best support the implementation of the Paris Agreement.

Several ICOS units provide their expertise 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, on $^{14}CO_2$ 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 NRT ICOS Atmosphere data for its use and that of other users. The data in the Copernicus service will be used, for example, by national weather services or private companies to improve air-pollution predictions and also to develop other data products using ICOS data, such as maps of fossil-fuel emissions.

Finally, ICOS has a unifying effect 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 science- and environment-related ministries who participate. Persons external to ICOS Member countries who were interviewed for the Impact Assessment in 2018 mention that the fact that states from the European Union have successfully come together to make a joint observation facility should not be underestimated and that getting people on the same page is very important and not trivial.

ICOS is increasing awareness of greenhouse gases

The most important external communications channel for ICOS, according to the Impact Assessment, is social media; Twitter, Instagram, YouTube and LinkedIn are used the most.

In July 2017, ICOS decided to use social media more efficiently to gain visibility for greenhouse gas measurements and climate change among a general audience. For that purpose, a social-media campaign, #ICOScapes, visited 12 stations – one in each ICOS country. The campaign is built on beautiful station photos and videos including station crew interviews on social media. For the still photos, a well-known professional nature photographer was enlisted. The campaign has been very successful, and the printed pictures are at the moment circling exhibitions around Europe.

In addition to multiplying ICOS' social-media coverage, the campaign has also connected the audience to ICOS, which is shown by the likes and positive comments received. Furthermore, on the photographer Konsta Punkka's Instagram account, #ICOScapes photos have gained between 35,500 and 91,000 likes each, as well as positive comments.

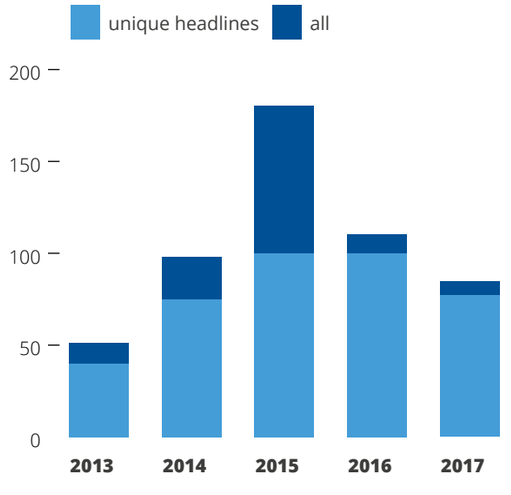
The number of general media articles concerning the ICOS RI has been around 90–100 annually since 2014 (Figure 11).

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. In the ICOS Impact Analysis interviews conducted in 2018, the industrial partners indicated that ICOS' high standards drive them to increase their product quality. The testing and calibration conducted at ICOS sites and the organisation of meetings and events were particularly mentioned.

Examples of cooperation between the industry and ICOS can be found in both the ATC and the ETC. 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. According to the Impact Assessment report, the industrial partners expect that the influence of ICOS on their market will increase when ICOS starts to publish data measured with their products.

Figure 11. The number of media articles mentioning ICOS in 2013–2017.



6 HOW TO BECOME AN ICOS ERIC MEMBER OR OBSERVER

A country can be either a Member or an Observer of ICOS ERIC. Both Member and Observer countries pay the annual contribution. Rights and obligations in ICOS ERIC depend on whether a country is a Member or an Observer. 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, Italy, the Netherlands, Norway, 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 National Network. Figure 12 summarises the process of becoming a Member or Observer.

Member application

When a country or intergovernmental organisation is interested in joining ICOS ERIC as a Member, it should as soon as possible 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 the ICOS RI. This will allow ICOS ERIC enough time to calculate the membership contributions and to plan the integration of the new stations into the ICOS station network with the Central Facilities.

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

During the process, an applicant that has expressed its desire to join ICOS ERIC will be invited to participate in General Assembly meetings as a guest even before the application letter is sent.

The application is to be made in writing, and it must be signed by an authority entitled to represent the country or the intergovernmental organisation on this matter.

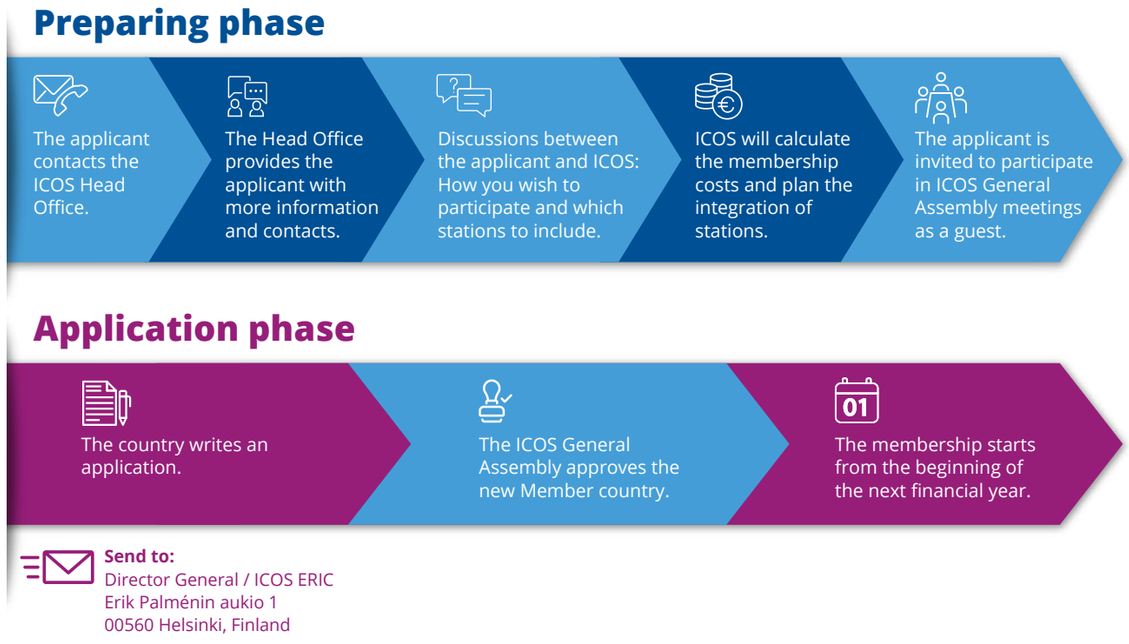
The application to become a Member should describe how the applicant will be involved in the ICOS RI and how it will participate in the realisation of the tasks and activities of ICOS ERIC according to the ICOS ERIC statutes, Article 2. It is especially important to list how many and what kind of stations 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 applicant should include information on its representing entities and list the names of its representatives in the General Assembly. Each Member is entitled to appoint up to three representatives.

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

Figure 12. Steps towards ICOS membership.



The application is addressed to the Chairperson of ICOS ERIC's General Assembly and sent to the Director General of ICOS ERIC at the address Erik Palménin aukio 1, 00560 Helsinki, Finland.

The admission of a new Member requires the approval of the ICOS ERIC General Assembly. The applicant is invited to join the General Assembly meeting. When approved, the Membership always starts at the beginning of the next financial year.

Observer application

According to the ICOS ERIC statutes, the terms of becoming an Observer are negotiated between the Observer and ICOS ERIC and endorsed by the General Assembly.

Therefore, when a country or an intergovernmental organisation is interested in joining ICOS ERIC as an Observer, it should as soon as possible contact the Head Office of ICOS ERIC to further discuss its plans. The terms of becoming an Observer are negotiated with the DG, who will keep the General Assembly informed.

In case the applicant is willing to participate in the realisation of the tasks and activities of ICOS ERIC, 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 the ICOS RI. This will allow ICOS ERIC enough time to calculate the observership contributions and to plan the integration of the potential new stations into the ICOS station network with the Central Facilities.

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

During the process, an applicant that has expressed its desire to join ICOS ERIC is invited to participate in General Assembly meetings as a guest even before the application letter is sent.

The application is to be made in writing, and it must be signed by an authority entitled to represent the country or the intergovernmental organisation on this matter.

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.

The application should also include a statement that the applicant fulfils the obligations of an Observer 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.

The application should include information on the representing entity and the name of the applicant's representative to the General Assembly. An Observer is entitled to appoint one representative.

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

The application is be addressed to the Chairperson of the ICOS ERIC General Assembly and sent to the Director General of ICOS ERIC at the address Erik Palménin aukio 1, 00560 Helsinki, Finland.

The admission of a new Observer and the obligations of an Observer require the approval of ICOS ERIC's General Assembly. The applicant will be invited to join the General Assembly meeting. When approved, the Observership always starts at the beginning of the next financial year.

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 134 (in January 2019) measuring stations located in twelve countries in Europe. ICOS member countries include Belgium, the Czech Republic, Denmark, Finland, France, Germany, Italy, the Netherlands, Norway, 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 Mediterranean. 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 twenty stations to less 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 and Ecosystem 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. Currently, in the Ocean network, only the term Class 1 is used.

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.

Chapter 5 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.

ICOS Belgium

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RV Simon Stevin and Thornton Buoy: two Ocean stations of ICOS Belgium.

The role of ICOS Belgium

Belgium is a small country and, with ten stations, probably has the densest National Network within ICOS. The Ecosystem stations of Brasschaat and Vielsalm have been collecting data for over two decades, making them two of the longest-running and most complete flux observation stations in the world.

The Ecosystem station of Lochristi is located in an 11 hectare bioenergy plantation of fast-growing poplars and is the only one of its kind in ICOS. Thanks to its location near the Thornton wind farm, the Thornton buoy is one of the very few fixed Ocean stations in the world that can rely on a Wi-Fi and mobile connection for reliable and fast data transmission.

The Maasmechelen station was constructed in 2015 in a heathland ecosystem in a national park in the eastern part of Belgium. It is the first European heathland where greenhouse gases are monitored. The station is closely linked to the Ecotron of Hasselt University, part of European ESFRI Infrastructure for Analysis and Experimentation on Ecosystems (AnaEE), since the ICOS observation station provides, in its chambers, the necessary data to control the environment.

In addition to the stations that collaborate within ICOS and other international research infrastructures, research vessel (RV) Simon Stevin is also used in ESFRI LifeWatch and the Brasschaat station is proposed as an eLTER site. The University of Antwerp is co-hosting the Ecosystem Thematic Centre (ETC) in conjunction with INRA in France and CMCC in Italy.

The ICOS Belgium Infrastructure

The ICOS Belgium network (Figures 13a, b) consists of 10 observation stations (Table 13) operated by six different research institutes. The University of Antwerp acts as the national Focal Point, representing and coordinating the Belgian network. Since the University of Antwerp is also co-hosting the Ecosystem Thematic Centre, it is particularly responsible for the collection and processing of ancillary data, one of the three pillars of the ETC, and for supporting and training the ecosystem community.

ICOS Belgium is involved in all three ICOS observation networks with six Ecosystem stations, three Ocean stations and one Atmosphere station. The Ecosystem station 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).

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

Until now, no structural funding has existed for the involvement of the Flemish partners in ICOS, but a yearly subsidy has been provided every year since

2012. In 2018, for the first time, the Research Foundation – Flanders (FWO) launched a call for structural funding for international research infrastructures, which ICOS Flanders applied for. This resulted in a two year grant for 2019–2020.

The University of Liège (uLiège) received funding in 2013 from the Service Public de Wallonie (DGO6, la Direction Générale Opérationnelle de l'Economie, de l'Emploi et de la Recherche) to finance three Ecosystem stations. The project, called ICOS Wallonia-Brussels, has a duration of eight years and is, in principle, renewable. In 2019 uLiège will apply for a renewal of the project for another period of eight years. The hope is to renew the project twice.

The RV Belgica, operated by RBINS-OD Nature, is funded by the Belgian Science Policy Office (BELSPO) via yearly renewed grants. The current grant will end on 30 November 2019. The atmosphere station at Ile de La Réunion has been operated by BIRA with financial support from the Belgian federal government since December 2014 through the ministerial decree for ICOS. The station is operated in collaboration with the French partners LSCE and Université de La Réunion; a partnership which is formalised in a Specific Cooperation Agreement that was signed by all parties in July 2018, with local support being provided by LACy – UMR 8105, Université de La Réunion.

By the end of November 2019, the federal cabinet expects to make a decision on a five-year extension of the support for ICOS.

13a

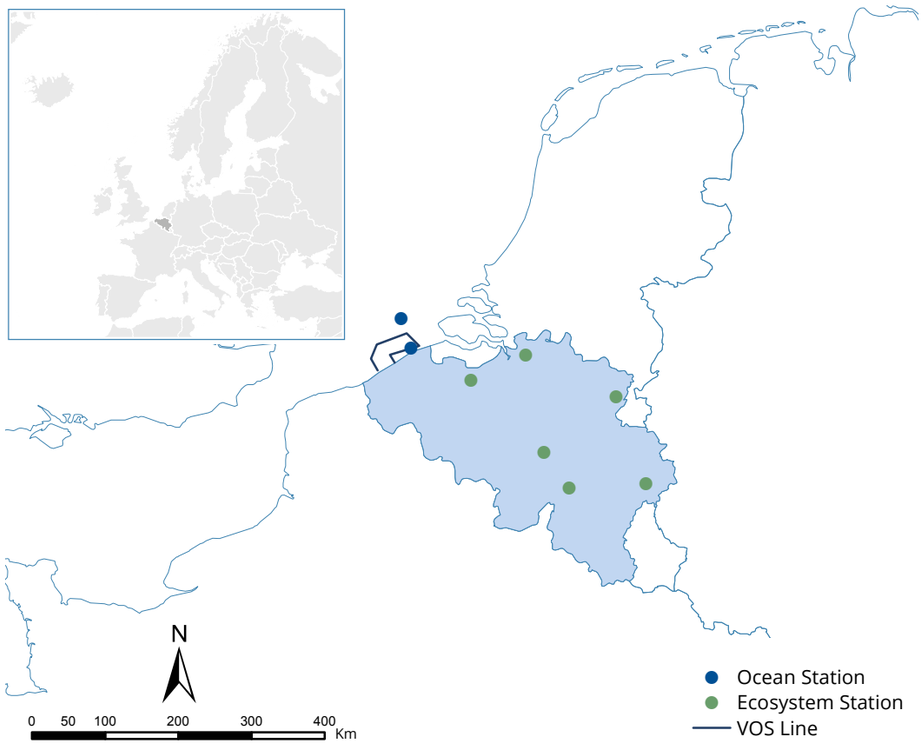

Figure 13: The ICOS Belgium station network. Figure 13a primarily covers Ecosystem and Ocean stations around mainland Belgium, while Figure 13b shows the remote Atmosphere station that is located in Saint-Denis in the Indian Ocean.

13b

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
www.vliz.be/en

Research Foundation – Flanders
www.fwo.be/en

Royal Belgian Institute for Space Aeronomy
www.aeronomie.be/en

Royal Belgian Institute of Natural Sciences
www.naturalsciences.be

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

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

University of Antwerp
www.uantwerpen.be/en

University of Liege
www.uliege.be

Table 13. ICOS Stations in Belgium

STATION NAME	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
Brasschaat	Ecosystem	Coniferous forest	Class 1	University of Antwerp
Dorinne	Ecosystem	Grassland	Class 2	University of Liege
Ile de La Réunion	Atmos-phere	Observatories in the Indian Ocean	Class 2	Royal Belgian Institute for Space Aeronomy
Lochristi	Ecosystem	Short rotation coppice	Class 1	University of Antwerp
Lonzée	Ecosystem	Cropland	Class 2	University of Liege
Maasmechelen	Ecosystem	Heathland	Class 2	University of Antwerp
RV Belgica	Ocean	Research vessel in the North Sea	Class 2	Royal Belgian Institute of Natural Sciences
RV Simon Stevin	Ocean	Research vessel in the North Sea	Class 1	Flanders Marine Institute
Thornton Buoy	Ocean	Buoy in the North Sea	Class 1	Flanders Marine Institute
Vielsalm	Ecosystem	Mixed forest	Class 2	University of Liege

ICOS Czech Republic

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Czech Republic

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Lanzhot: 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, a Global Change Research Institute in 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 14; Table 14), 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 Křešín Atmosphere station near Pacov 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 (CO2, CH4, CO, N2O, SF6), 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 roadmap, 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 14: The ICOS Czech Republic station network.

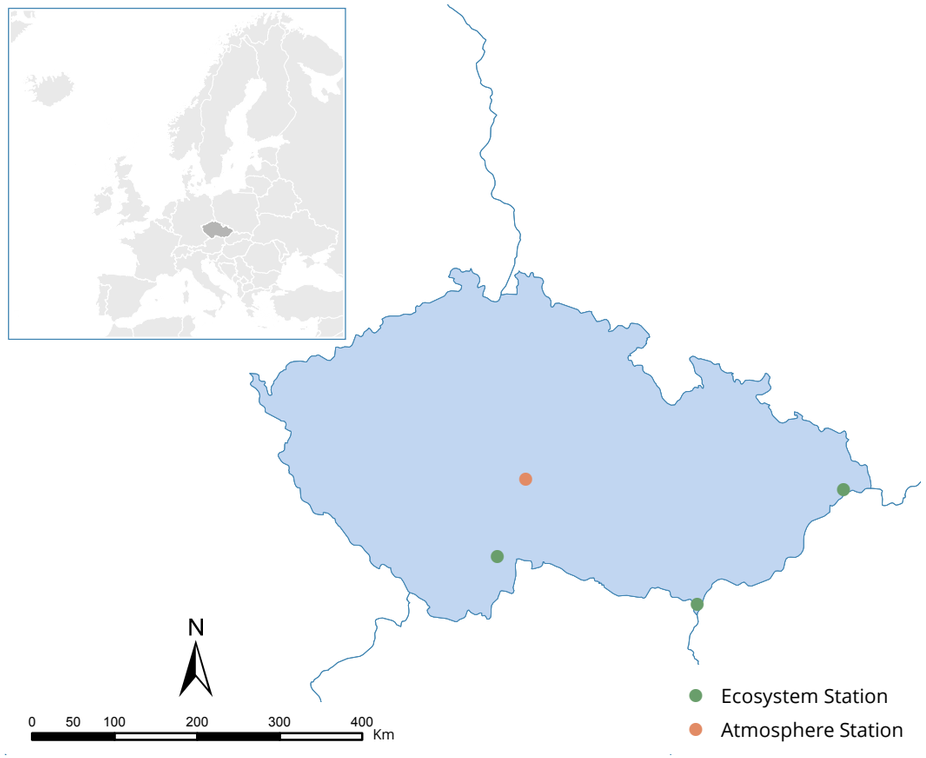

Table 14. ICOS Stations in the Czech Republic

STATION NAME	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
Bílý Kříž forest	Ecosystem	Forest	Class 1	CzechGlobe
Křešín u Pacova	Atmosphere	Tall tower	Class 2	CzechGlobe
Lanzhot	Ecosystem	Forest	Class 1	CzechGlobe
Trebon	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 eleven stations (Figures 15a, b; Table 15), of which one is an Atmosphere station and ten 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 (2016–2021) 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 Agency of Science, Technology and Innovation

Ministry of Higher Education and Science
www.ufm.dk/en

Roskilde University
www.ruc.dk/en

Technical University of Denmark
www.dtu.dk/english

University of Copenhagen
www.ku.dk/english

Figure 15: The ICOS Denmark station network. Figure 15a shows Ecosystem stations located in mainland Denmark, while Figure 15b depicts both Atmosphere and Ecosystem stations situated in Greenland.

15a

15b

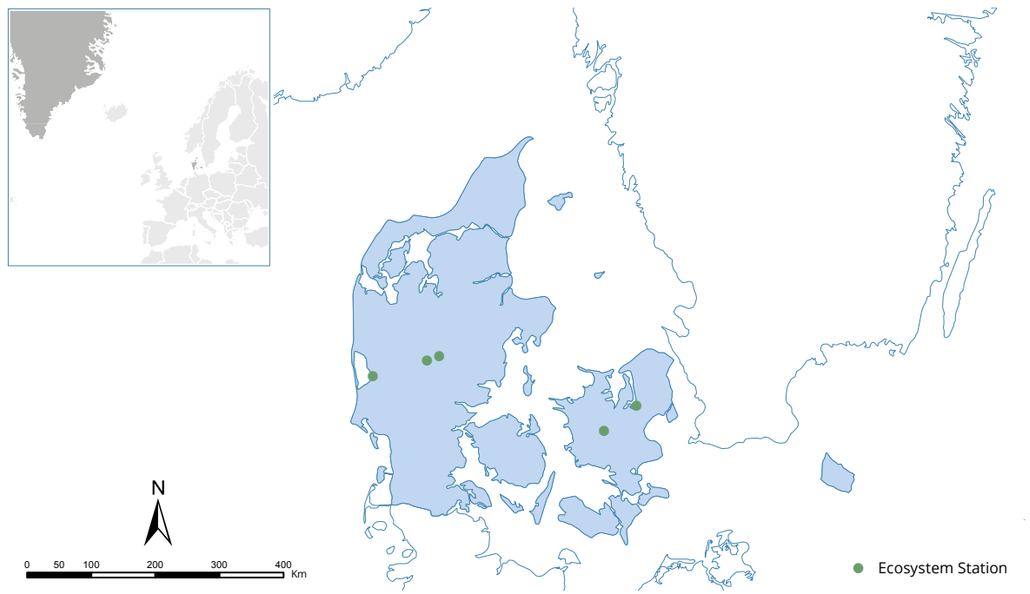

Table 15. ICOS Stations in Denmark

STATION NAME	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
Disko*	Ecosystem	Heathland	Associated	University of Copenhagen
Gludsted Plantage	Ecosystem	Forest	Associated	University of Copenhagen
Nuuk Fen*	Ecosystem	Mire	Associated	University of Copenhagen
Nuuk Heath*	Ecosystem	Heathland	Associated	Aarhus University
Risoe	Ecosystem	Forest	Associated	Technical University of Denmark
Skjern	Ecosystem	Wetland	Associated	University of Copenhagen
Soroe	Ecosystem	Deciduous forest	Class 1	Technical University of Denmark
Station Nord*	Atmos-phere	High arctic, dry and cold	Class 2	Aarhus University
Voulundgaard	Ecosystem	Conventional agriculture	Class 1	University of Copenhagen
Zackenberg Fen*	Ecosystem	Wetland	Class 2	Aarhus University
Zackenberg Heath*	Ecosystem	Grassland	Associated	Aarhus University

*The station is located in Greenland.

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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. 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. The Finnish stations represent the boreal and sub-arctic Eurasian environments with both east-west and north-south transitions in eco-climatic features. ICOS Finland studies the sinks and sources of greenhouse gases in typical boreal ecosystems, focusing on coniferous forests and peatlands but also including the unique sites of a lake and an urban environment.

ICOS-FI provides the longest-running CH_4 EC and CO_2 EC flux records from its two stations at Siikaneva and Kuivajärvi. Hyytiälä SMEAR II station, in turn, is the flagship station of the SMEAR network, providing versatile information for several fields of science.

The ICOS Finland infrastructure

ICOS Finland was established by, and its management board is formed by, the University of Helsinki (UHEL), the Finnish Meteorological Institute (FMI) and the University of Eastern Finland (UEF). The ICOS Finland network consists of thirteen stations (Figure 16; Table 16), of which four are Atmosphere stations, four Ecosystem stations, and five Associate Ecosystem stations.

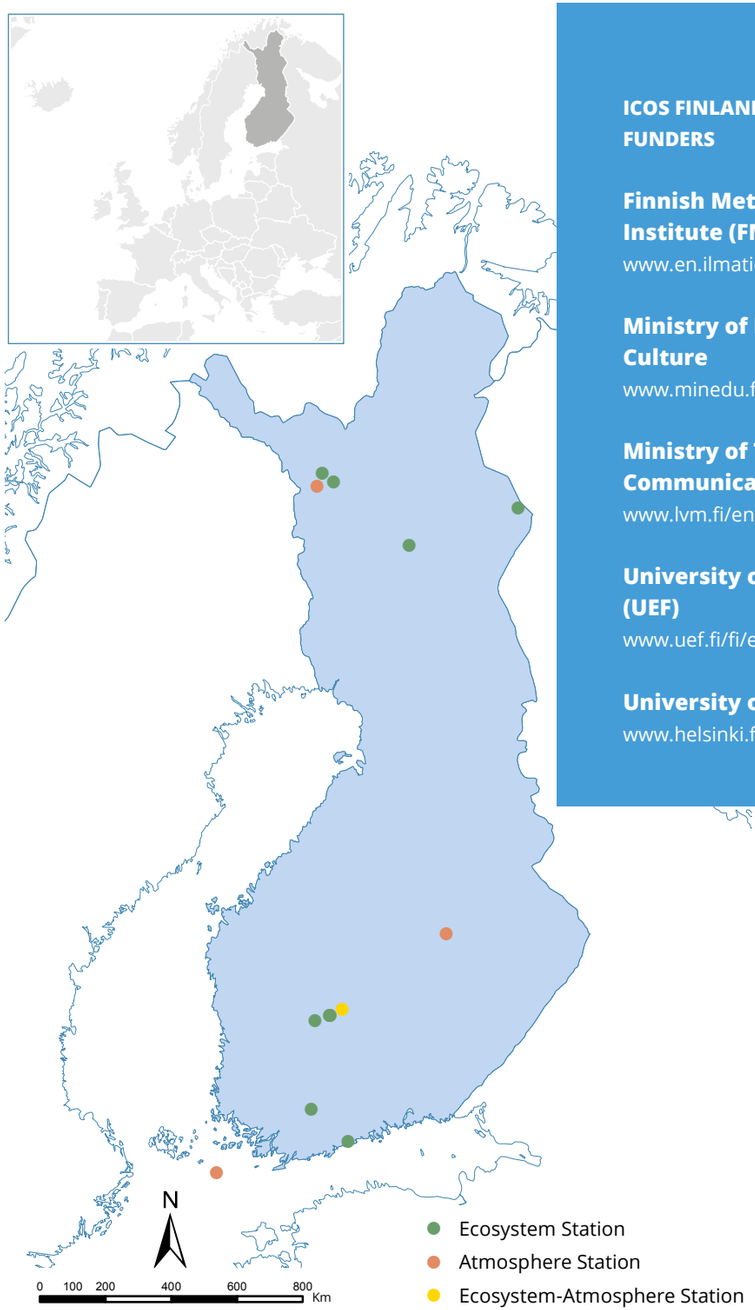
Seven of the ICOS Finland stations also belong to the Stations for Measuring Earth Surface–Atmosphere Relations (SMEAR) network. Four ICOS-FI stations are part of Pallas-Sodankylä Global Atmosphere Watch of the World Meteorological Organization (GAW) station operated by the FMI.

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

In addition to the data on sensible heat flux, latent heat flux (evapotranspiration) and various meteorological and ecophysiological (vegetation and soil) variables are available, together with essential metadata. During the last five years, the Hyytiälä ICOS ECO data alone has been downloaded over 2,000 times from the main databases. 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

The funding for the ICOS-FI activities is provided by the Academy of Finland, the University of Helsinki, the University of Eastern Finland and the Finnish Meteorological Institute. The Academy of Finland, the University of Helsinki and the University of Eastern Finland share 50 percent of the total funding and the Finnish Meteorological Institute covers the remaining 50 percent. ICOS-FI has received funding from the Academy of Finland since 2010. A minimum of 50 percent of the total funding is used for equipment.



ICOS FINLAND PARTNERS AND FUNDERS

Finnish Meteorological Institute (FMI)
www.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 16: The ICOS Finland station network.

Table 16. ICOS Stations in Finland

STATION NAME	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
Hyytiälä/SMEAR II	Atmos-phere	Tall tower/southern boreal pine forest	Class 1	University of Helsinki
Hyytiälä/SMEAR II	Ecosystem	Southern boreal pine forest	Class 1	University of Helsinki
Kenttärova	Ecosystem	Northern spruce forest	Associated	Finnish Meteorological Institute
Kuivajärvi	Ecosystem	Boreal lake	Associated	University of Helsinki
Kumpula, Helsinki/SMEAR III	Ecosystem	Urban environment	Associated	University of Helsinki
Lettosuo	Ecosystem	Forestry-drained peatland	Associated	Finnish Meteorological Institute
Lompolojänkkä	Ecosystem	Northern boreal fen	Class 2	Finnish Meteorological Institute
Pallas-Sammaltunturi (Pallas-Sodankylä GAW)	Atmos-phere	Sub-arctic hill	Class 1	Finnish Meteorological Institute
Puijo/SMEAR IV	Atmos-phere	Tall tower/urban environment	Class 2	Finnish Meteorological Institute and University of Helsinki
Siikaneva	Ecosystem	Southern boreal fen	Class 2	University of Helsinki
Sodankylä forest (Pallas-Sodankylä GAW)	Ecosystem	Northern boreal pine forest	Class 1	Finnish Meteorological Institute
Utö Atmospheric and Marine Research Station	Atmos-phere	Non-forested island in Baltic sea	Class 2	Finnish Meteorological Institute
Värriö/SMEAR I	Ecosystem	Subarctic pine forest	Associated	University of Helsinki

ICOS France

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Saclay: an Atmosphere station of ICOS France.

The role of ICOS France

Within ICOS RI, the France network aims to provide the dataflow required for quantifying and understanding the greenhouse gas exchanges 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 mires) and is spread over temperate, alpine, Mediterranean and tropical climates.

The ICOS France network includes a range of intensive management from annual crops to grazed or mowed meadows, fast growing pine forest plantations to managed broadleaved forests, unmanaged pristine forests and mires. Innovative measurement methods and techniques are developed and tested at ICOS French stations; for example, total carbon column with Fourier transform spectrometers, greenhouse gas atmospheric profiles 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 is managing the Atmosphere Thematic Centre (ATC) located at Saclay and a part of the Ecosystem Thematic Centre (ETC) chemical analysis laboratories of ICOS RI.

ICOS France infrastructure

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

The ICOS France network is organized into three ICOS observation domains: Atmosphere, Ecosystem and Ocean. The France network consists of 22 stations (Figures 17 a, b, c, d.) of which four are Atmosphere stations, seventeen are Ecosystem stations and one is an Ocean station (voluntary observation ship, VOS). 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 infra-

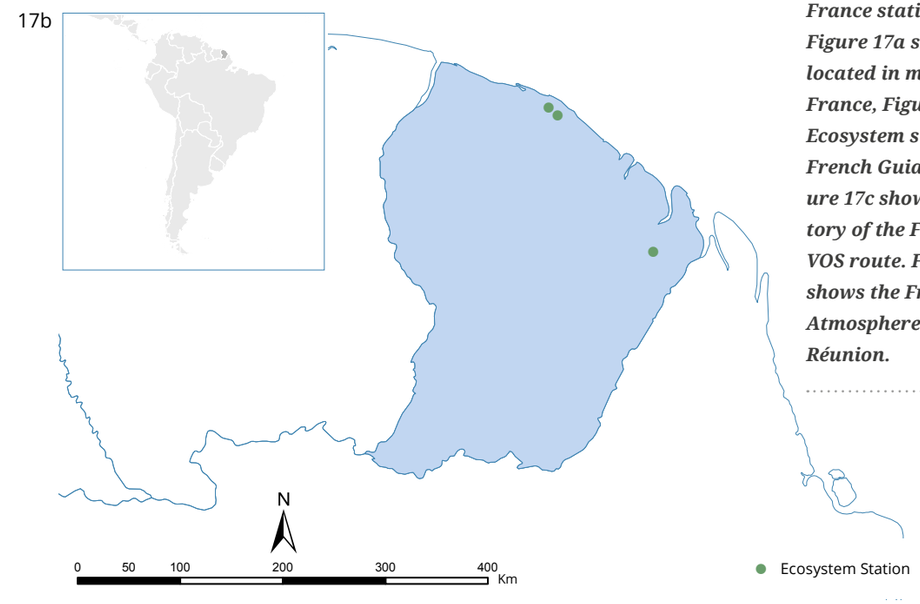
structure and are committed for a period of 20 years.

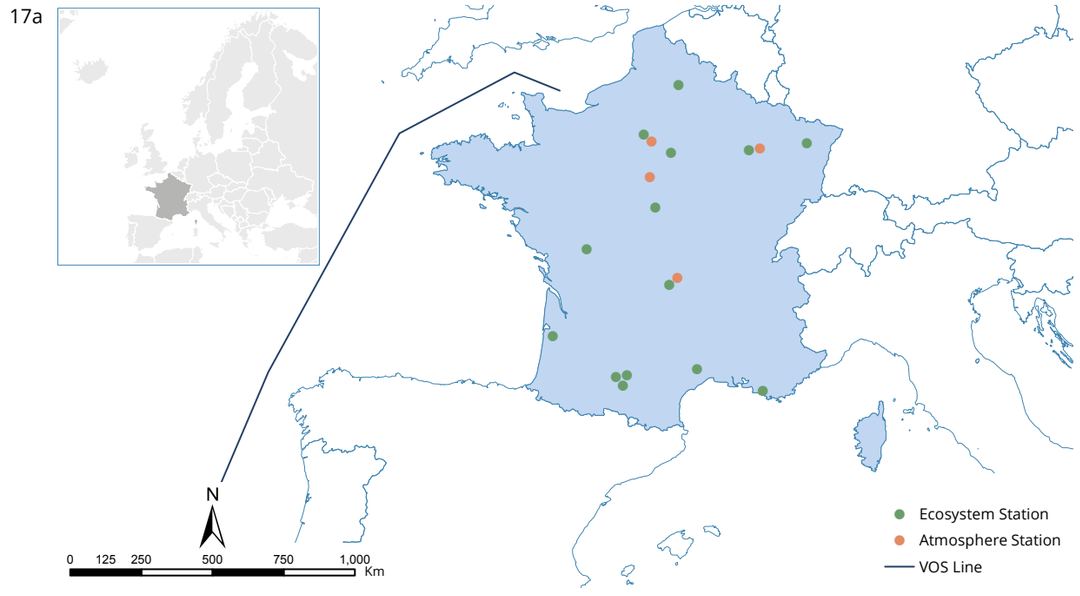
In addition to the stations, France is hosting the Atmosphere Thematic Centre at Saclay (CEA-CNRS-UVSQ) and, in coordination with Italy and the University of Antwerp, is part of the Ecosystem Thematic Centre (INRA) including the ICOS plant and soil analysis laboratories in Bordeaux and Arras, respectively, and the European Soil Conservatory in Orléans.

The ICOS France funding structure

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

Altogether, the host institutions employ 90 permanent staff members devoted to the station network, and Thematic Centres employ a manpower equivalent of 45 full-time employees. They also provide supporting units with funds covering equipment, consumables, travel and other expenses. The French network of stations receives additional grants directly from the Research and Higher Education Ministry for either Research–Observation networks or the Future Investment Plan (PIA), and from the national (French) ANR for international research projects.





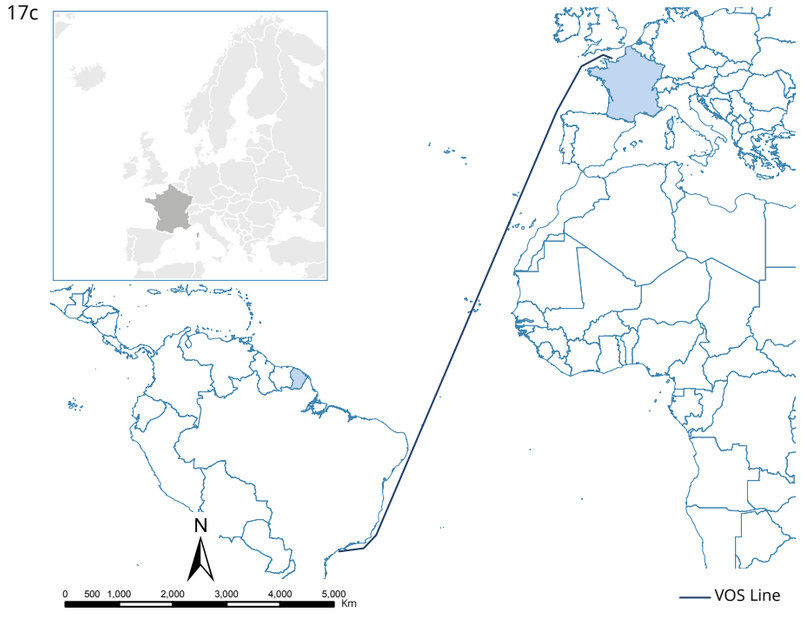
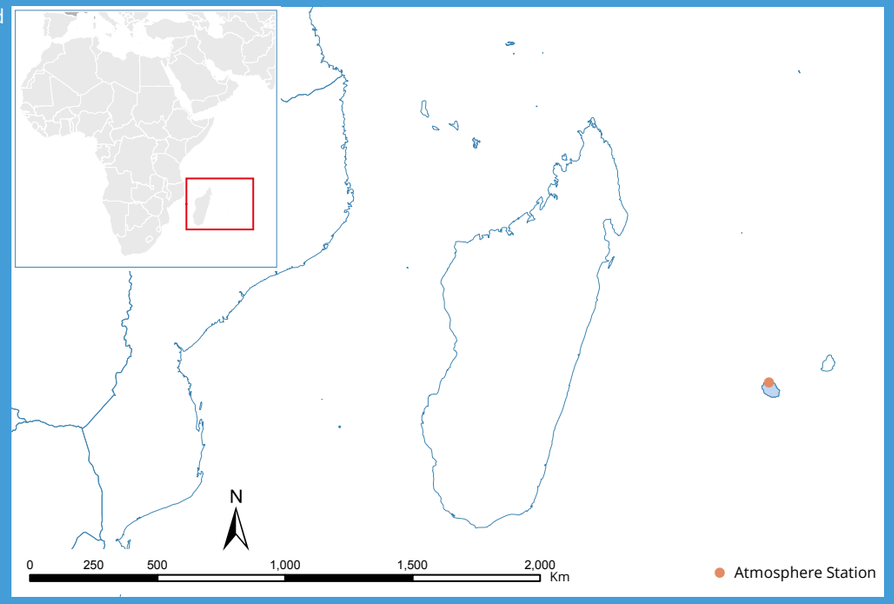


Figure 17: The ICOS France station network. Figure 17a shows stations located in metropolitan France, Figure 17b depicts Ecosystem stations in French Guiana, and Figure 17c shows the trajectory of the France-Brazil VOS route. Figure 17d shows the Franco-Belgium Atmosphere station on La Réunion.

17d



ICOS FRANCE PARTNERS AND FUNDERS

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

French Geological Survey (BRGM)
www.brgm.eu/

French Meteorological Institute
www.meteofrance.com/

French National Institute for Agricultural Research (INRA)
www.institut.inra.fr/en

French National Museum of Natural History
www.mnhn.fr/

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

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

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

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

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

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/

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

Table 17. ICOS stations in France

STATION NAME	STATION CODE	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
Auradé	Ecosystem	Cropland	Class 2	The National Centre for Scientific Research	ANDRA
Bilos - Salles	Ecosystem	Forest	Class 2	French National Institute for Agricultural Research	CEA-CNRS
Carpagg	Ecosystem	Grassland	Associated	CIRAD-INRA	CEA-CNRS-UVSQ
Estrées-Mons A28	Ecosystem	Cropland	Associated	French National Institute for Agricultural Research	CEA-CNRS
Font-Blanche	Ecosystem	Forest	Associated	French National Institute for Agricultural Research	U. La Réunion
Fontainebleau-Barbeau	Ecosystem	Forest	Class 1	The National Centre for Scientific Research	CNRS
France-Brazil Voluntary Observing Ship	Ocean	VOS	Class 1	CNRS-IRD-U. Paris-Sorbonne	INRA
Grignon	Ecosystem	Cropland	Class 2	French National Institute for Agricultural Research	INRA
Guyaflux	Ecosystem	Forest	Associated	French National Institute for Agricultural Research	INRA
Hesse	Ecosystem	Forest	Class 1	French National Institute for Agricultural Research	CNRS
La Guette	Ecosystem	Mire	Associated	The National Centre for Scientific Research	INRA

Table 17. ICOS stations in France

STATION NAME	STATION CODE	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
Lamasquère	Ecosystem	Cropland	Class 1	The National Centre for Scientific Research	INRA
Laqueuille	Ecosystem	Grassland	Class 1	French National Institute for Agricultural Research	CNRS
La Réunion	Atmosphere	Tall tower	Class 2	University of La Réunion	CNRS
Lusignan	Ecosystem	Grassland	Class 2	French National Institute for Agricultural Research	INRA
Montiers sur Saulx	Ecosystem	Forest	Class 2	French National Radioactive Waste Management Agency	INRA
Nouragues	Ecosystem	Forest	Associated	The National Centre for Scientific Research	ANDRA
Puechabon	Ecosystem	Forest	Class 2	The National Centre for Scientific Research	CNRS
Puy de Dôme	Atmosphere	Mountain	Class 2	CEA-CNRS	CNRS- Météo-France
Saclay	Atmosphere	Tall tower	Class 1	CEA-CNRS-UVSQ	CNRS-IRD-U. Paris-Sorbonne
Toulouse	Ecosystem	Grassland	Associated	CNRS- Météo-France	CIRAD-INRA
Trainou	Atmosphere	Tall tower	Class 2	CEA-CNRS	INRA
Observatoire Pérenne de l'Environnement	Atmosphere	Tall tower	Class 1	French National Radioactive Waste Management Agency	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. The location and site management of the Fendt measuring station represents 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 Laboratory. 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, policy makers and the public.

The ICOS Germany infrastructure

ICOS Germany comprises 29 stations (Figures 18a, b; Table 18), and they are categorized into three station/observation networks: Atmosphere, Ecosystem and Ocean. The network is operated by thirteen 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 nine observation stations at tall towers 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 15 stations with the use of the eddy covariance technique. The flux stations are 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 VOS (voluntary observation ship) lines in the North Atlantic Ocean and Baltic Sea in addition to the research vessel '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 of Transport and Digital Infrastructure (BMVI) and Education and Research (BMBF). Further funding is provided in-kind by the member institutions.

ICOS GERMANY PARTNERS AND FUNDERS

Alfred Wegener Institute (AWI)
www.awi.de/en.html

Dresden University of Technology
www.tu-dresden.de

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

Federal Ministry of Transport and Digital Infrastructure (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.heidelberg.edu

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

Jülich Research Centre (FZJ)
www.fz-juelich.de/portal/DE/Home/home_node.html

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

Thünen Institute
www.thuenen.de/en

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

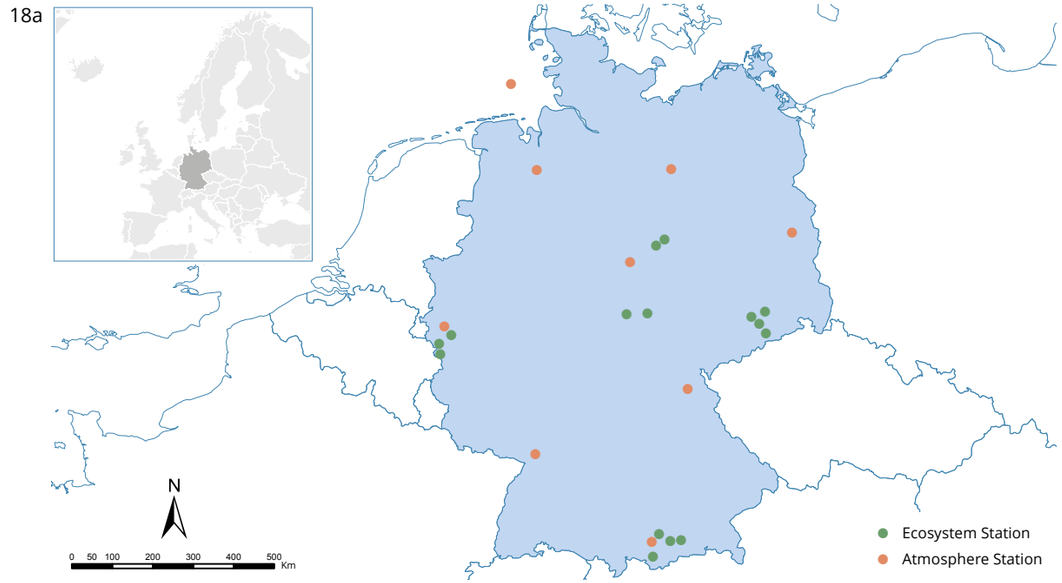


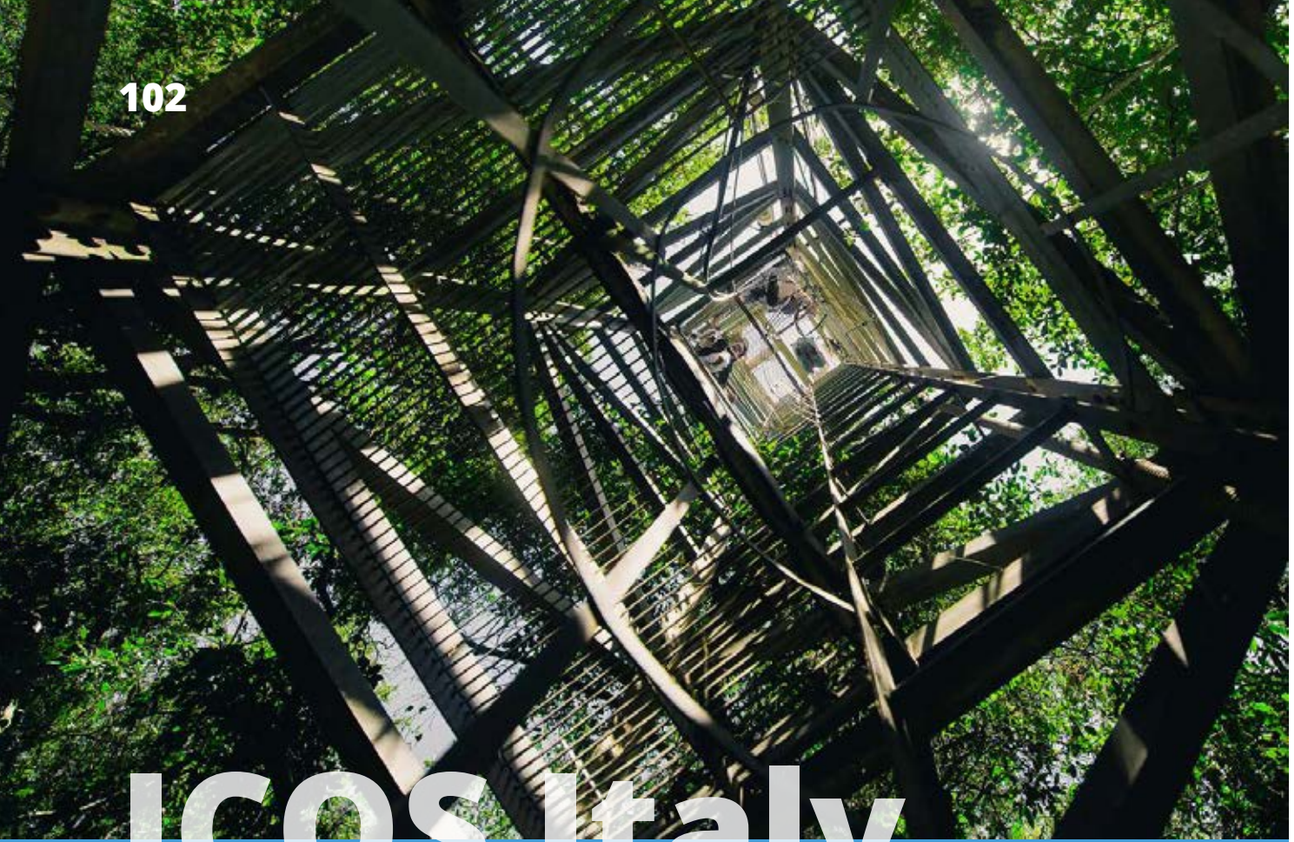
Figure 18: The ICOS Germany station network. Figure 18a shows the stations in mainland Germany, while Figure 18b depicts remote Ocean stations and VOS lines.

Table 18. ICOS Stations in Germany

STATION NAME	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
Cape Verde Ocean Observatory	Ocean	Profiling station	Class 1	GEOMAR - Helmholtz Centre for Ocean Research Kiel
Finnmaid VOS	Ocean	VOS line	Class 1	Leibniz Institute for Baltic Sea Research Warnemünde
Fendt	Ecosystem	Grassland	Class 1	Karlsruhe Institute of Technology
Gartow	Atmosphere	Tall tower	Class 1	German Weather Service (DWD)
Gebesee	Ecosystem	Cropland	Class 1	Thünen Institute of Climate-Smart Agriculture
Graswang	Ecosystem	Grassland	Associated	Karlsruhe Institute of Technology
Grillenburg	Ecosystem	Grassland	Associated	Dresden University of Technology
Grosses Bruch	Ecosystem	Grassland	Associated	Helmholtz Centre for Environmental Research
Hainich	Ecosystem	Deciduous forest	Associated	Max Planck Institute
Hausgarten	Ocean	Profiling station	Class 1	Alfred-Wegener-Institut (AWI)
Helgoland	Atmosphere	Tall tower	Class 2	German Weather Service (DWD)
Hetzdorf	Ecosystem	Plantation forest (oaks)	Associated	Dresden University of Technology
Hohenpeissenberg	Atmosphere	Tall tower	Class 1	German Weather Service (DWD)
Hohes Holz	Ecosystem	Deciduous forest	Class 1	Helmholtz Centre for Environmental Research
Jülich	Atmosphere	Tall tower	Class 1	German Weather Service (DWD)

Table 18. ICOS Stations in Germany

STATION NAME	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
Karlsruhe	Atmosphere	Tall tower	Class 1	German Weather Service (DWD)
Klingenberg	Ecosystem	Cropland	Associated	Dresden University of Technology
Lindenberg	Atmosphere	Tall tower	Class 1	German Weather Service (DWD)
Mooseurach	Ecosystem	Coniferous bog forest	Associated	Weihenstephan-Triesdorf University of Applied Sciences
North Atlantic VOS	Ocean	VOS line	Class 1	GEOMAR - Helmholtz Centre for Ocean Research Kiel
Ochsenkopf	Atmosphere	Tall tower	Class 1	German Weather Service (DWD)
Polarstern Research Vessel	Ocean	Research vessel	Class 1	Alfred-Wegener-Institut (AWI)
Rollesbroich	Ecosystem	Grassland	Associated	Jülich Research Centre (FZJ)
Schechenfilz	Ecosystem	Coniferous bog forest	Associated	Karlsruhe Institute of Technology
Selhausen Jülich	Ecosystem	Cropland	Class 1	Jülich Research Center (FZJ)
Steinkimmen	Atmosphere	Tall tower	Class 2	German Weather Service (DWD)
Tharandt	Ecosystem	Coniferous forest	Class 1	Dresden University of Technology
Torfhaus	Atmosphere	Tall tower	Class 2	German Weather Service (DWD)
Wüstebach	Ecosystem	Deciduous forest	Associated	Jülich Research Centre (FZJ)



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 has one of the most southerly ICOS stations in Europe: Castelporziano. The nature reserve at Castelporziano is covered with 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 reserve assist 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.

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 is divided into three ICOS observation networks: Atmosphere, Ecosystem, and Ocean. ICOS Italy network consists of 16 stations (Figure 19; Table 19), of which three are Atmosphere stations, five are Ecosystem stations, four are Associate Ecosystem stations and four are Ocean stations.

The University of Viterbo hosts the Ecosystem Thematic Centre (ETC) together with the Euro-Mediterranean Center on Climate Change (CMCC), the University of Antwerp in Belgium and the Institut National de la Recherche Agronomique (INRA) in Bordeaux, France.

In the coming years, thanks to the project 'Upgrading ICOS-Italy Observation Network in the Mediterranean–Pa (PRO-ICOS_MED)', many stations, especially those based in the South of Italy, will be 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.

The ICOS Italy funding structure

The main Italian funds derive from the Ministry of Universities 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 characterized by personnel and owned instrumentation.

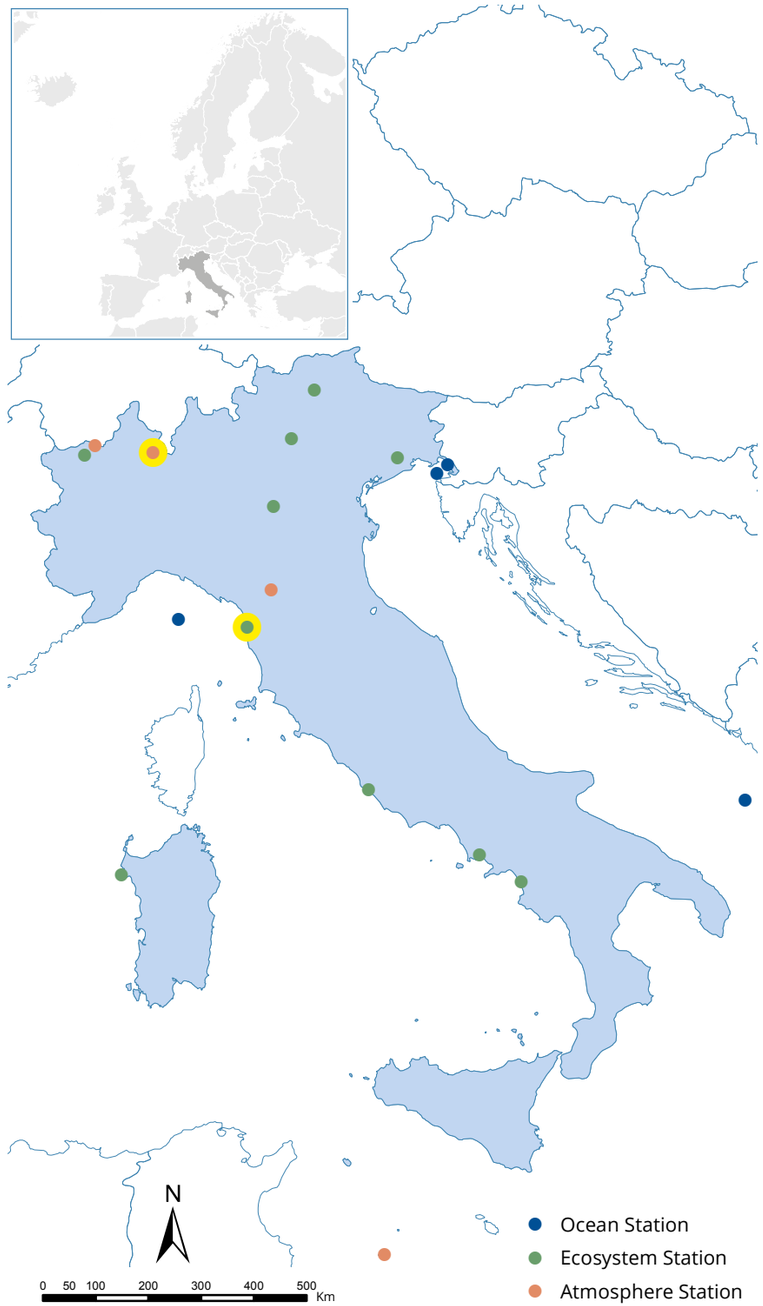

Figure 19: The ICOS Italy station network. Atmosphere station Ispra (IPR) and Ecosystem station San Rossore 2 (IT-SR2) are run by the Joint Research Centre and they are highlighted on the map.

ICOS ITALY PARTNERS AND FUNDERS

Agenzia regionale protezione ambiente (ARPA)
www.arpa.piemonte.it/english-version

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

Italian Research Council (CNR), Dipartimento Scienze del Sistema Terra e Tecnologie per l'Ambiente
www.dta.cnr.it/index.php/it

Ministry of Education, Universities and Research, Department for the universities and higher education establishments in art, music and dance
www.miur.gov.it

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

South Tyrolean State Administration
www.provinz.bz.it/de/default.asp

The Edmund Mach Foundation
www.fmach.it

The University of Genoa
www.unige.it

The University of Padova
www.unipd.it/en

The University of Sassari
www.en.uniss.it

The University of Udine
www.uniud.it

Universita Cattolica
www.unicatt.it

University of Tuscia (UNITUS)
www.unitus.it

Table 19. ICOS Stations in Italy

STATION NAME	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
Arca di Noe (IT-Noe)	Ecosystem	Shrubland	Associated	University of Sassari
Borgo Cioffi – (IT-BCi)	Ecosystem	Cropland	Class 1	National Research Council of Italy
Bosco Fontana – (IT-BFt)	Ecosystem	Oak-Hornbeam forest	Associated	Università Cattolica del Sacro Cuore
Capodimonte – (IT-PCm)	Ecosystem	Urban park	Associated	National Research Council - Institute of Research on Terrestrial Ecosystems (IRET)
Castelporziano 2 – (IT-Cp2)	Ecosystem	Mediterranean forest	Class 1	Council for Agricultural Research and Economics (CREA)
E2M3A	Ocean	Surface buoy	Class 1	OGS Section of Oceanography – ExO Group
Lampedusa (Lmp)	Atmosphere	Open ocean	Class 2	National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)
Lison - (IT-Lsn)	Ecosystem	Vineyard	Class 2	University of Padova and University of Udine

Table 19. ICOS Stations in Italy

STATION NAME	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
Miramare (IT-Mambo1)	Ocean	Surface buoy	Class 1	OGS Section of Oceanography
Monte Bondone – (IT-MBo)	Ecosystem	Grassland	Class 2	Fondazione Edmund Mach
Monte Cimone (IT-CMN)	Atmosphere	Mountain peak	Class 2	Italian Air Force and
PALOMA	Ocean	Beacon	Class 1	National Research Council-Institute of Marine Science
Plateau Rosa (IT-PRS)	Atmosphere	Mountain peak	Class 2	Ricerca sul Sistema Energetico -RSE S.p.A.
Renon – Selva Verde – (IT-Ren)	Ecosystem	Subalpine forest	Class 2	Forest Services of the Autonomous Province of Bolzano
Torgnon – (IT-Tor)	Ecosystem	Alpine grassland	Associated	Environmental Protection Agency of Aosta Valley (ARPA VdA)
W1M3A	Ocean	Surface buoy	Class 1	National Research Council of Italy

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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-NL aims to ultimately establish high observational density and high-resolution inversion modelling, enabling 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-NL also plays an important role in the Carbon Portal, providing a multitude of data services for all 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

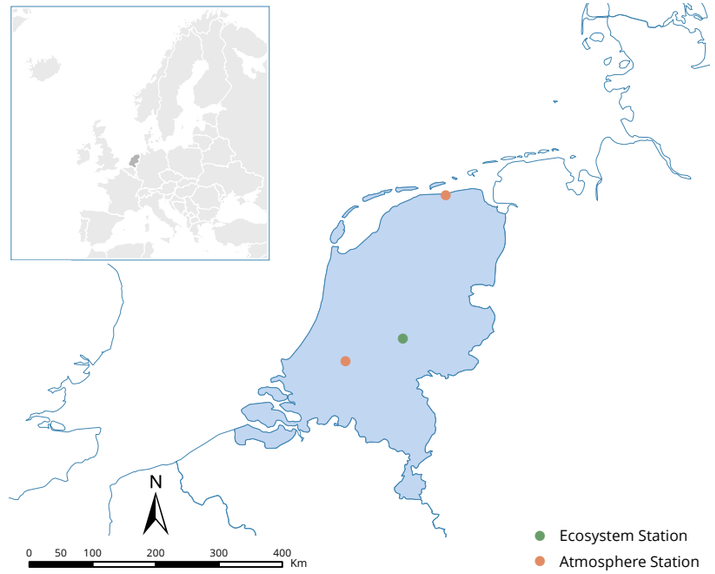


Figure 20: The ICOS Netherlands station network.

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

The ecosystem station Loobos Pinus sylvestris will enter the Class 2 labelling programme during 2019. 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-meter tower at the edge of the tidal Wadden sea/mud flats and the Cabauw tower is a 200-meter 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.

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 new large-scale Netherlands 'Ruisdael' observatory, 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/

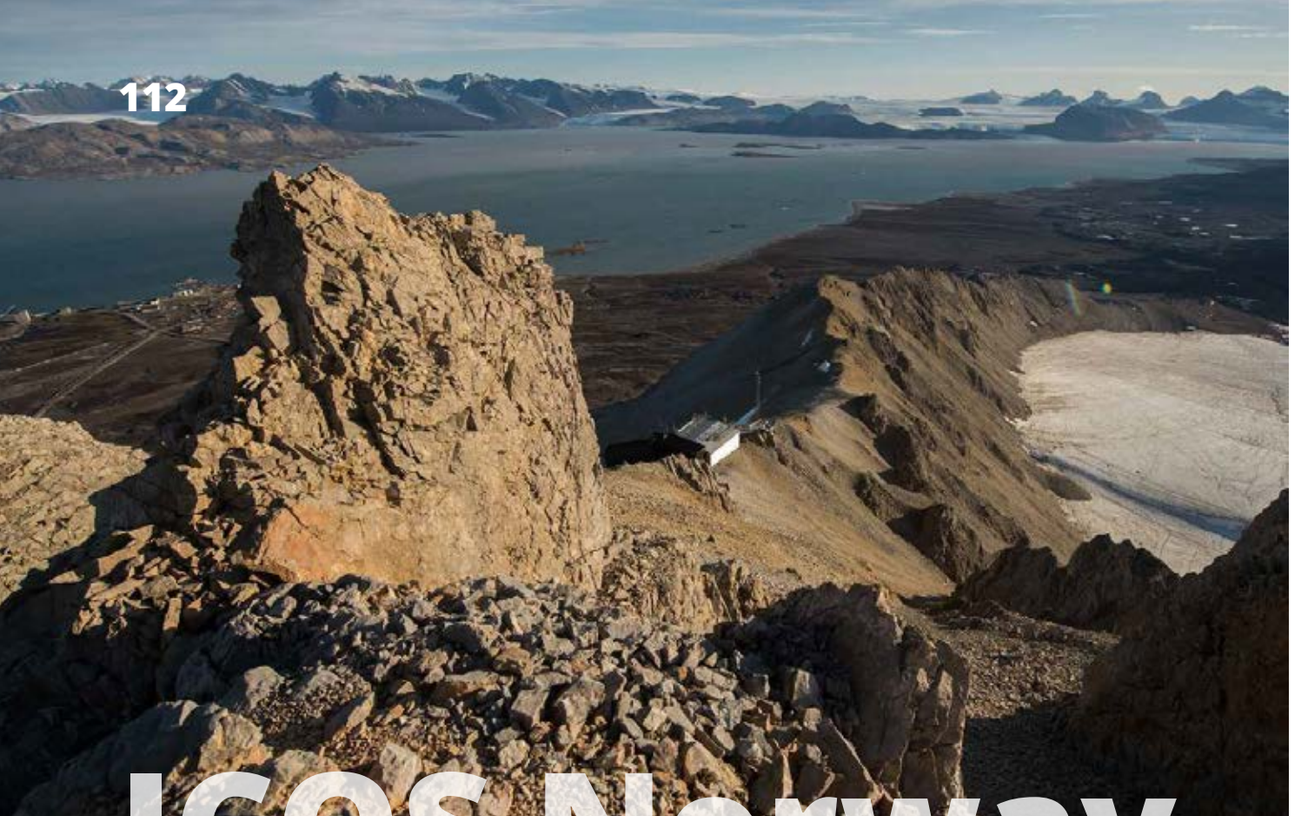
University of Wageningen (WUR)
www.wur.nl/

Utrecht University
www.uu.nl/en

Vrije Universiteit Amsterdam
www.vu.nl/en/

Table 20. ICOS Stations in the Netherlands

STATION NAME	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
Cabauw	Atmosphere	Tall tower	Class 2	KNMI/TNO
Loobos	Ecosystem	Pine Forest	Associated	University of Wageningen
Lutjewad	Atmosphere	Coastal/continental	Class 2	University of Groningen



ICOS Norway

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The Zeppelin Observatory: an Atmosphere station of ICOS Norway.

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 four out of the 21 permanent Ocean stations and 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): four 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 four 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 Nor-

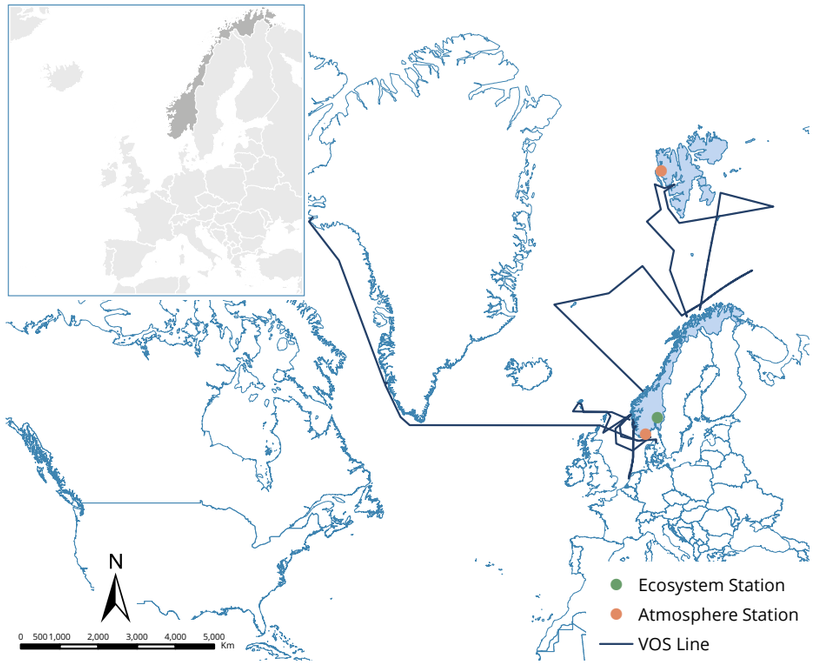

Figure 21: The ICOS Norway station network showing the stations located in mainland Norway, remote Atmosphere stations and VOS lines.

wegian Institute for Air Research (NILU), provides 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

The ICOS Norway station network is funded by the Research Council of Norway (RCN) through a research infrastructure project running from 2016–2021. 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 domain, the RCN also funds operating costs, such as maintenance of the instruments, daily operations and data analysis. For the Atmosphere and Ecosystem 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).

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 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

STATION NAME	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
Birkenes Observatory	Atmosphere	Hilly forest, meadow, lakes	Class 2	Norwegian Institute for Air Research
Hurdal	Ecosystem	Norway spruce forest	Class 2	Norwegian Institute of Bioeconomy Research
MV Nuka Arctica	Ocean	VOS, northern North Atlantic	Class 1	University of Bergen
MV Trans Carrier	Ocean	VOS, North Sea	Class 1	NORCE Norwegian Research Centre
RV G. O. Sars	Ocean	VOS, Nordic Seas	Class 1	NORCE Norwegian Research Centre
RV Kronprins Haakon	Ocean	VOS, Arctic Ocean	Class 1	Norwegian Polar Institute
Zeppelin Observatory	Atmosphere	Remote arctic, mountainous	Class 1	Norwegian Institute for Air Research

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 one Ocean station. 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 destabilize carbon stored in boreal forest soils, accelerate degradation of the mires and acidification of the seas, with 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 is located in Sweden and it is run by Sweden in conjunction with Netherlands. Carbon Portal acts as the platform for observational data and elaborated data products of the ICOS RI.

The ICOS Sweden infrastructure

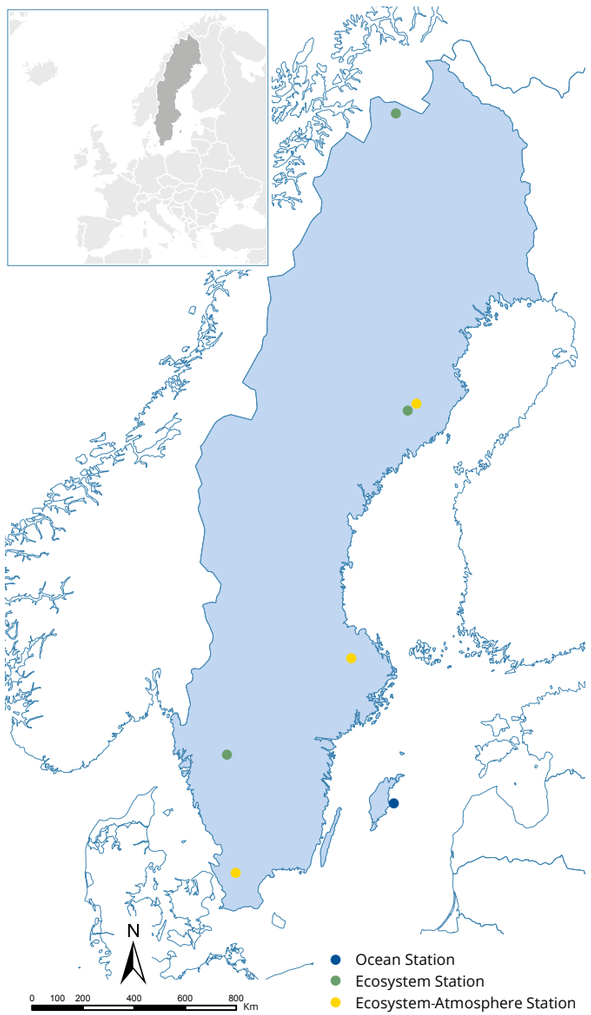
ICOS Sweden is a national research infrastructure consisting of a consortium of five partners: Lund University, Gothenburg University, the Swedish University of Agricultural Sciences, Uppsala University, and the Swedish Polar Research Secretariat. Lund University hosts the consortium and the coordination 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 and earth systems science.

ICOS Sweden contributes to observations in all three ICOS observation networks: Atmosphere, Ecosystem, and Ocean. The ICOS Sweden network consists of 10 stations (Figure 22; Table 22), of which six are Ecosystem stations representing boreal forests and boreal to subarctic mires, and one is an Ocean station, representing the Baltic Sea. The three Atmosphere stations are co-located with the three forest Ecosystem stations.

The ICOS Sweden research infrastructure is already in place and has been in operation at most stations since 2014. Three stations have longer measurement records: Norunda 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 Ocean station measures meteorological variables, together with the concentration and fluxes of CO2 and other gases from ocean surface waters and the near-surface atmosphere.

All three Atmosphere stations received the ICOS RI label in spring 2018 and the Hyltemossa and Norunda Ecosystem stations received the ICOS RI label in spring and autumn 2018, respectively. The remaining stations are expected to get labeled in 2019-2020. All pre-labeled and labeled data is delivered through the ICOS Carbon Portal. Several of the stations are co-located with other research infrastructures such as ACTRIS, SITES (a national research infrastructure for terrestrial and limnologic field research) and NordSpec (a research network for spectral data collection).

Figure 22: The ICOS Sweden station network.



ICOS SWEDEN PARTNERS AND FUNDERS

Swedish Polar Research Secretariat
polar.se/en

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

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

University of Gothenburg
www.gu.se/english

University of Lund
www.lunduniversity.lu.se

Uppsala University
www.uu.se/en

The ICOS Sweden funding structure

Funding for the construction and operations of ICOS Sweden is provided by the Swedish Research Council and the consortium partners. The Swedish Research Council covers, for the present funding period (2016–2020), around 40 percent of the costs, while the consortium partners together cover 60 percent of the funding. ICOS Sweden will apply for renewed funding in 2019 to cover the period of 2021–2024.

Table 22. ICOS Stations in Sweden

STATION NAME	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
Abisko-Stordalen	Ecosystem	Sub-arctic fen	Class 2	Swedish Polar Research Secretariat
Degerö	Ecosystem	Boreal fen	Class 2	Swedish University of Agricultural Sciences
Hyltemossa	Atmosphere	Tall tower	Class 1	Lund University
Hyltemossa	Ecosystem	Temperate spruce	Class 2	Lund University
Mycklemossen	Ecosystem	Hemi-boreal fen	Class 2	University of Gothenburg
Norunda	Atmosphere	Tall tower	Class 1	Lund University
Norunda	Ecosystem	Hemi-boreal pine/spruce	Class 2	Lund University
Svartberget	Atmosphere	Tall tower	Class 1	Swedish University of Agricultural Sciences
Svartberget	Ecosystem	Boreal pine/spruce	Class 2	Swedish University of Agricultural Sciences
Östergarnsholm	Ocean	Coastal Baltic Sea	Class 1	Uppsala University

ICOS Switzerland

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www.gl.ethz.ch/research/bage/icos-ch.html

Jungfraujoch: the Atmosphere station of ICOS Switzerland.

The role of ICOS Switzerland

The ICOS Switzerland (ICOS-CH) consortium is part of ICOS RI with two Class 1 stations, both of which are unique in terms of their geographical location, site history and relevance for national and international research. Switzerland, with its exceptional geographic location in the central part of the Alps, is an outstanding node within the ICOS RI network.

The ICOS Jungfraujoch station, located at 3,580 metres above sea level, is the highest measurement station in the ICOS network. The Alpine region is particularly affected by climate change because a warming climate leads to glacier retreat, thawing of permafrost and related consequences such as changes in the regional water cycle, rock falls and landslides.

Due to its elevation and distance from major greenhouse gas sources and sinks, ICOS Jungfraujoch station is mainly exposed to air masses representing background conditions over Central Europe. Occasionally, air pollution can also be observed at Jungfraujoch when air from lower atmospheric layers reaches the station. By analysing these special events, the unique location of ICOS Jungfraujoch allows the unravelling of different greenhouse gas sources and sink areas over a large part of Central Europe.

ICOS-CH is continuously working on increasing the value of the two Swiss ICOS stations that are outside the ICOS network. Synergies with national and international networks and research infrastructures are pursued; for example, with ACTRIS (Aerosols, Clouds and Trace Gases Research Infrastructure) or eLTER (European Long-term Ecosystem Research in Europe).

The ICOS Switzerland infrastructure

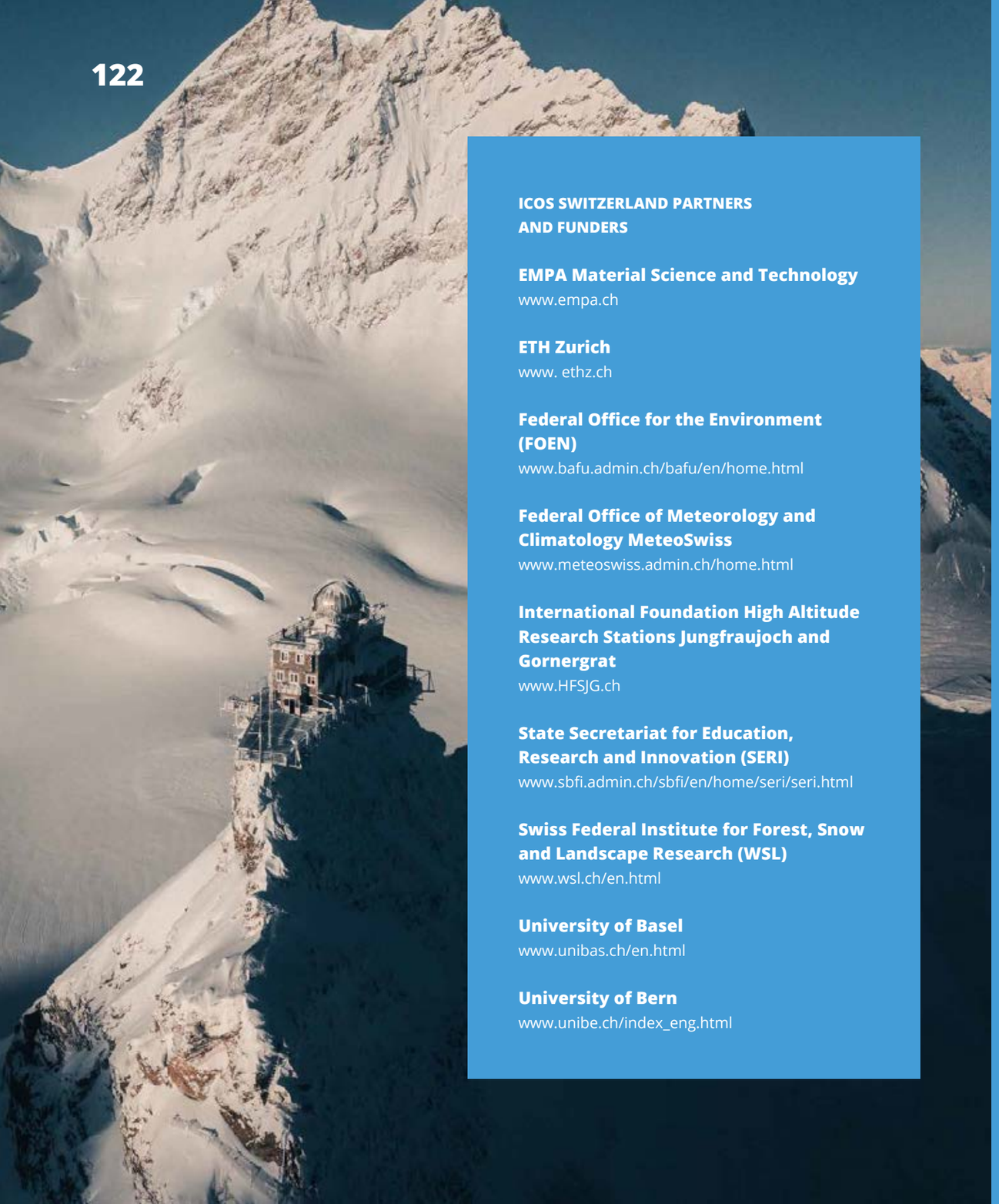
The ICOS Switzerland (ICOS-CH) consortium consists of ETH Zürich, Empa, WSL, the University of Bern, the University of Basel, and MeteoSwiss.

ICOS Switzerland contributes to two ICOS RI observation networks and consists of one Atmosphere station (Jungfraujoch, JFJ) and one Ecosystem station (Davos, DAV) (Figure 23; Table 23). Jungfraujoch is the highest, permanently manned research station in Europe and, since 1974, has measured local trace elements. Its greenhouse gas measurements started in 1973 at an altitude of 3,580 meters above sea level. In addition, JFJ is frequently exposed to air masses decoupled from the lowermost atmospheric layer and thus provides information on the background conditions over Central Europe, which is of key importance in quantifying emission strengths in more polluted environments.

By contrast, Davos (DAV) is the only subalpine spruce forest (1,639 metres above sea level) within ICOS RI and is one of the oldest ecosystem flux sites globally (with a record of eddy covariance measurements since 1997). This allows detection of the impact of slow changes in climate over time. The long-term data of the two stations is openly available, not only to scientists but also to other user communities and stakeholders.

The ICOS Switzerland funding structure

ICOS-CH is funded by the European Commission (Preparatory Phase, 2008–2012), the Swiss National Science Foundation and in-house contributions (Implementation Phase, since 2013).



ICOS SWITZERLAND PARTNERS AND FUNDERS

EMPA Material Science and 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
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

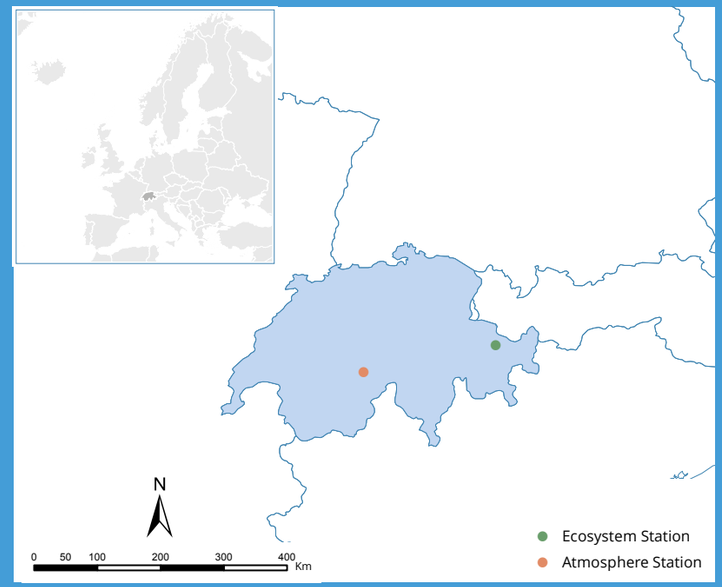
University of Basel
www.unibas.ch/en.html

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

Table 23. ICOS Stations in Switzerland

STATION NAME	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
Davos	Ecosys-tem	Subalpine forest	Class 1	ETH Zürich, the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), the Swiss Federal Laboratories of Material Sciences & Technology (Empa), and the National Air Pollution Monitoring Network (NABEL/FOEN)
Jungfrau-joch	Atmos-phere	Alpine mountain	Class 1	High Altitude Research Stations Jungfraujoch & Gornergrat (HFSJG), the University of Bern, the Swiss Federal Laboratories of Material Sciences & Technology (Empa), National Air Pollution Monitoring Network (NABEL/FOEN), MeteoSwiss and the University of Basel

Figure 23: The ICOS Switzerland station network.



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 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 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 (Table 24; Figure 24). At present, ICOS UK has one Ecosystem station (Auchencorth Moss, led by the

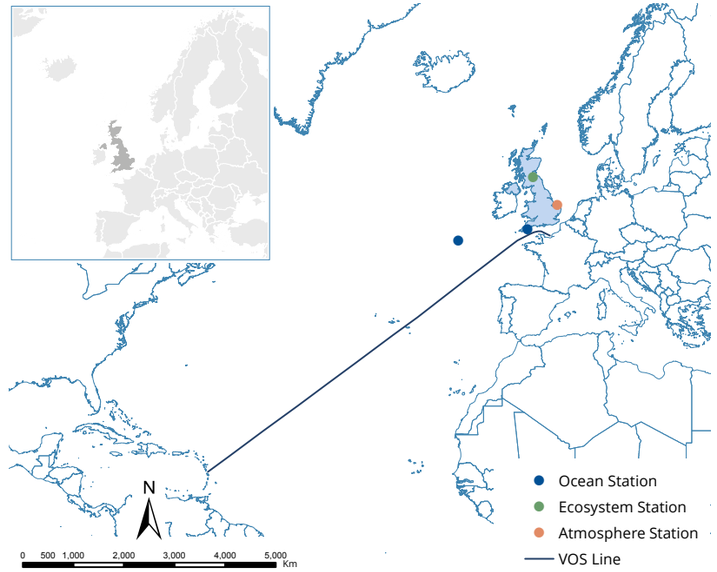

Figure 24: The ICOS UK station network showing stations located around mainland UK and the route across the North Atlantic Ocean for the UK-Caribbean VOS line.

Centre of Ecology & Hydrology); one Atmosphere station (led by the University of East Anglia) and three Ocean stations: the UK-Caribbean VOS line (led by the University of Exeter); the Western Channel Observatory (led by Plymouth Marine Laboratory) and a buoy, the PAP-SO (maintained by the National Oceanography Centre).

The UK-Caribbean VOS line (University of Exeter) is a monthly east-west route, during which the ship collects pCO_2 data in collaboration with 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, located at 49° N, 16.5° W, collects high frequency surface and sub-surface CO_2 data (National Oceanography Centre).

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

The University of Exeter (UoE)
www.exeter.ac.uk

University of East Anglia
www.uea.ac.uk

Table 24. ICOS Stations in the United Kingdom

STATION NAME	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
Auchencorth Moss	Ecosystem	Peatland	Class 1	Centre for Ecology and Hydrology
PAP Sustained Observatory	Ocean	Ocean mooring and surface buoy, NW Atlantic	Class 1	National Oceanography Centre (NOC) and the MET Office
UK – Caribbean VOS line	Ocean	VOS, UK – Caribbean	Class 1	University of Exeter and the NOC
Western Channel Observatory	Ocean	Ocean mooring and surface buoy, NW Atlantic	Class 1	Plymouth Marine Laboratory
Weybourne	Atmosphere	Coastal	Class 2	National Centre for Atmospheric Science and the University of East Anglia

8 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.
DANUBIUS-PP	DANUBIUS-PP is an EU Horizon 2020 project to raise DANUBIUS-RI (the International Centre for Advanced Studies on River-Sea Systems) to the legal, financial and technical maturity required for its successful implementation and development.
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.
ENVRI-FAIR	ENVRI-FAIR is a 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 aim is to provide an open-access platform for interdisciplinary environmental research data in the European Research Area utilising the EOSC.
ENVRIplus	ENVRIplus is a Horizon 2020 project bringing together Environmental and Earth System Research Infrastructures, projects and networks along with technical specialist partners to create a more coherent, interdisciplinary and interoperable cluster of Environmental Research Infrastructures across Europe.
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 vapor and energy between terrestrial ecosystems and the atmosphere.
Head Office	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 ERIC Operational Unit.

TERMS	DEFINITIONS
ICOS Research Infrastructure (ICOS RI)	The distributed research infrastructure that is coordinated by ICOS ERIC and involves Central Facilities and ICOS NNs.
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 RI Committee)	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 standardized 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 atmospheric stations.) Has complete equipment for measuring the full set of ICOS core parameters.
ICOS Class 2 Station	(For ecosystem and atmospheric stations.) Has the same analytical precision as a Class 1 station but measures fewer physical parameters than a Class 1 station.
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).
Operational Unit	An essential component of ICOS ERIC for the operations of the ICOS RI (such as the Head Office and the Carbon Portal).
RISCAPE	European Research Infrastructures in the International Landscape – RISCAPE – is a Horizon 2020-funded project to map the international landscape of RIs, in particular in respect to the major European RIs.
VERIFY	VERIFY is a Horizon 2020 project that aims to provide a pre-operational, observation-based system for the monitoring and verification of greenhouse gases (GHGs).

Abbreviations

ACRONYMS	ABBREVIATIONS
^{14}C	Radiocarbon
$^{14}CO_2$	Carbon dioxide containing a heavy isotope of carbon
AGU	American Geophysical Union
ATC	ICOS Atmosphere Thematic Centre
CAL	ICOS Central Analytical Laboratory
CAMS	Copernicus Atmosphere Monitoring Service
CEOS	Earth Observation Satellites
CFs	ICOS Central Facilities, i.e., ATC, ETC, OTC, CAL
CH_4	Methane
CMCC	Euro-Mediterranean Centre on Climate Change
CO	Carbon monoxide
COP23	The informal name for the 23rd 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
ENVRI	European Environmental Research Infrastructures
ERIC	European Research Infrastructure Consortium
ESFRI	European Strategy Forum on Research Infrastructures

ACRONYMS	ABBREVIATIONS
ETC	ICOS Ecosystem Thematic Centre
FCL	Flask and Calibration Laboratory of CAL
FOS	Fixed Ocean Stations
GAW	Global Atmosphere Watch programme (WMO programme)
GCOS	Global Climate Observing System
GEO	Group on Earth Observations
GEO-C	Group on Earth Observations-Carbon
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 RI Committee	ICOS Research Infrastructure Committee
IG3IS	Integrated Global Greenhouse Gas Information System
INRA	National Institute for Agricultural Research, France
IOCCP	International Ocean Carbon Coordination Project
IPCC	Intergovernmental Panel on Climate Change
ISIC	ICOS Interim Stakeholder Council
IW	Internal Working data

Abbreviations

ACRONYMS	ABBREVIATIONS
KPI	Key Performance Indicator
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
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
QA/QC	Quality Assurance/Quality Control
SAB	Scientific Advisory Board
SBSTA	Subsidiary Body for Scientific and Technical Advice
SF_6	Sulphur hexafluoride
SOCAT	Surface Ocean CO_2 Atlas
TCs	Thematic Centres for Atmosphere, Ecosystem and Ocean observations (ATC, ETC and OTC)
UNFCCC	United Nations' Framework Convention on Climate Change
UNITUS	University of Tuscia, Italy
VOS	Voluntary Observation Ships
WMO	World Meteorological Organisation

The most significant EU projects of ICOS in 2019

PROJECT ACRONYM	DEFINITION/ABBREVIATION
DANUBIUS-PP	DANUBIUS-PP is an EU Horizon 2020 project to raise DANUBIUS-RI (the International Centre for Advanced Studies on River-Sea Systems) to the legal, financial and technical maturity required for successful implementation and development.
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.
ENVRIplus	ENVRIplus is an EU Horizon 2020 project bringing together Environmental and Earth System Research Infrastructures, projects and networks along with technical specialist partners to create a more coherent, interdisciplinary and interoperable cluster of Environmental Research Infrastructures across Europe.
RINGO	RINGO (Readiness of ICOS for Necessities of Integrated Global Observations) is an EU Horizon 2020 project with five principal objectives: scientific, geographical, technological, data and political/administrative readiness.
RISCAPE	European Research Infrastructures in the International Landscape (RISCAPE) is an EU Horizon 2020-funded project to map the international landscape of RIs, in particular in respect to the major European RIs.
SEACRIFOG	Supporting EU-African Cooperation on Research Infrastructures for Food Security and Greenhouse Gas Observations. SEACRIFOG is an EU Horizon 2020 project that aims to improve coherence and increase the exchange and use of information between RIs in Europe and Africa as well as to enhance technical competence, science awareness and lifelong learning in Africa.
VERIFY	VERIFY is an EU Horizon 2020 project that aims to provide a pre-operational, observation-based system for the monitoring and verification of greenhouse gases (GHGs).

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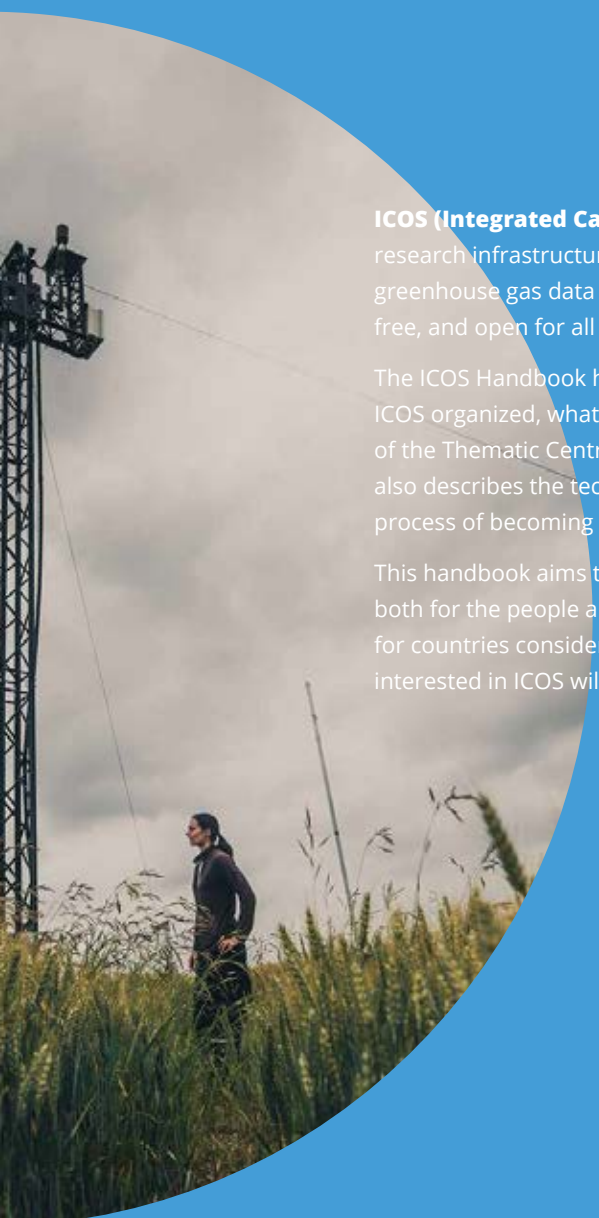
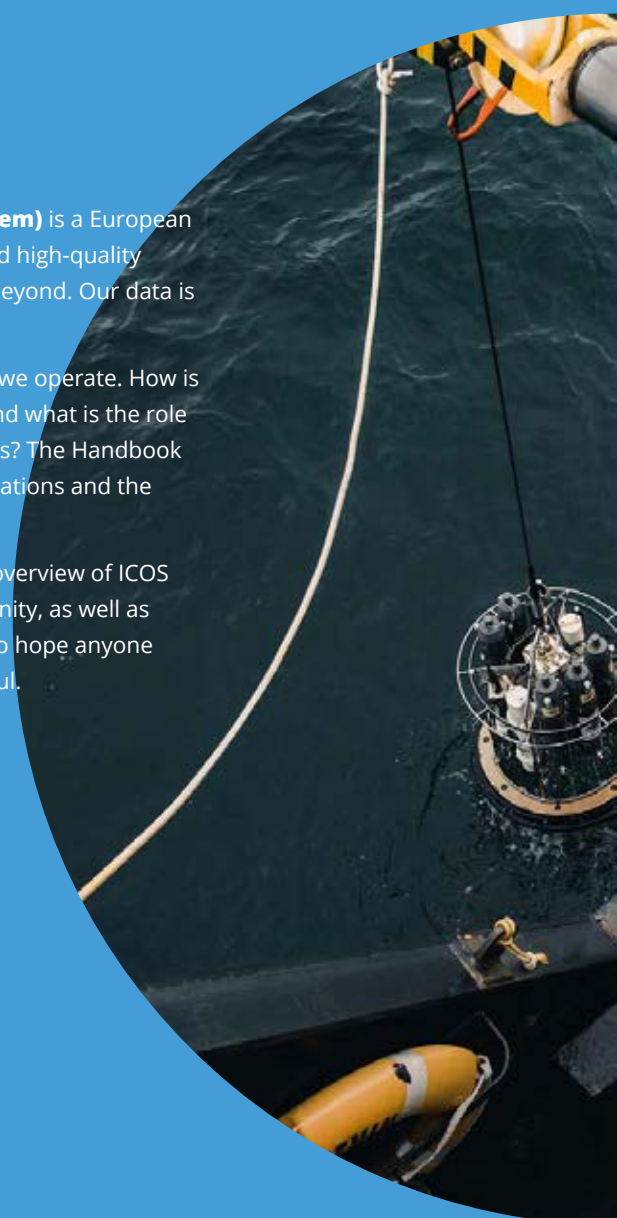
Greenhouse gases in the atmosphere increase constantly, heating up our planet. To predict climate change and mitigate its consequences, it is important to observe greenhouse gases and their circulation between air, land and sea.



ICOS (Integrated Carbon Observation System) is a European research infrastructure producing standardised high-quality greenhouse gas data in our 12 countries and beyond. Our data is free, and open for all users.

The ICOS Handbook helps to understand how we operate. How is ICOS organized, what and how 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 countries considering membership. We also hope anyone interested in ICOS will find this handbook useful.



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