ICOS Handbook

2020

Knowledge through observations

ICOS Integrated Carbon Observation System

ICOS Handbook 2020

Author:

Integrated Carbon Observation System (ICOS) Research Infrastructure

ICOS ERIC

Helsinki 2020

ICOS HANDBOOK 2020

Author: Integrated Carbon Observation System Research Infrastructure

Developed on behalf of the Integrated Carbon Observation System Research Infrastructure by the ICOS ERIC

Editors: Edited based on the ICOS Handbook 2019 by Katri Ahlgren and Mari Keski-Nisula, ICOS Communications

Maps: Karolina Pantazatou, Alex Vermeulen, ICOS Carbon Portal

Layout: Inka Kosonen

The ICOS Handbook 2020 is based on the ICOS Handbook 2019, funded by the RINGO project. The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730944

Published by ICOS ERIC, Helsinki, June 2020

2nd rev. ed.

Printed in Finland by PunaMusta

ISBN 978-952-69501-0-5 (paperback)

ISBN 978-952-69501-1-2 (PDF)

For copies and information: icos-comms@icos-ri.eu

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 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, to today's operational Landmark Infrastructure which has been identified by COPERNICUS as an integral part of the European CO_2 Monitoring and Verification Support Capacity. Building a greater ICOS community together e.g. with scientists, technicians and our stakeholders, has been the base of our success. We are proud and grateful for this achievement.

And we have even more ambitions: ICOS has also developed strong cooperation beyond Europe, is an officially accredited Observer of the UNFCCC and a Participating Organisation in GEO. Through this cooperation we are aiming towards a global operational observing system that supports the Paris Agreement with data on greenhouse gas data, carbon-climate feedbacks and direct observations of anthropogenic emissions.

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 National Networks and the process for a country to participate in this research infrastructure. Novel in this edition, we have added those prospective member countries, Spain and Poland, that have announced their intention to join ICOS ERIC in 2020.

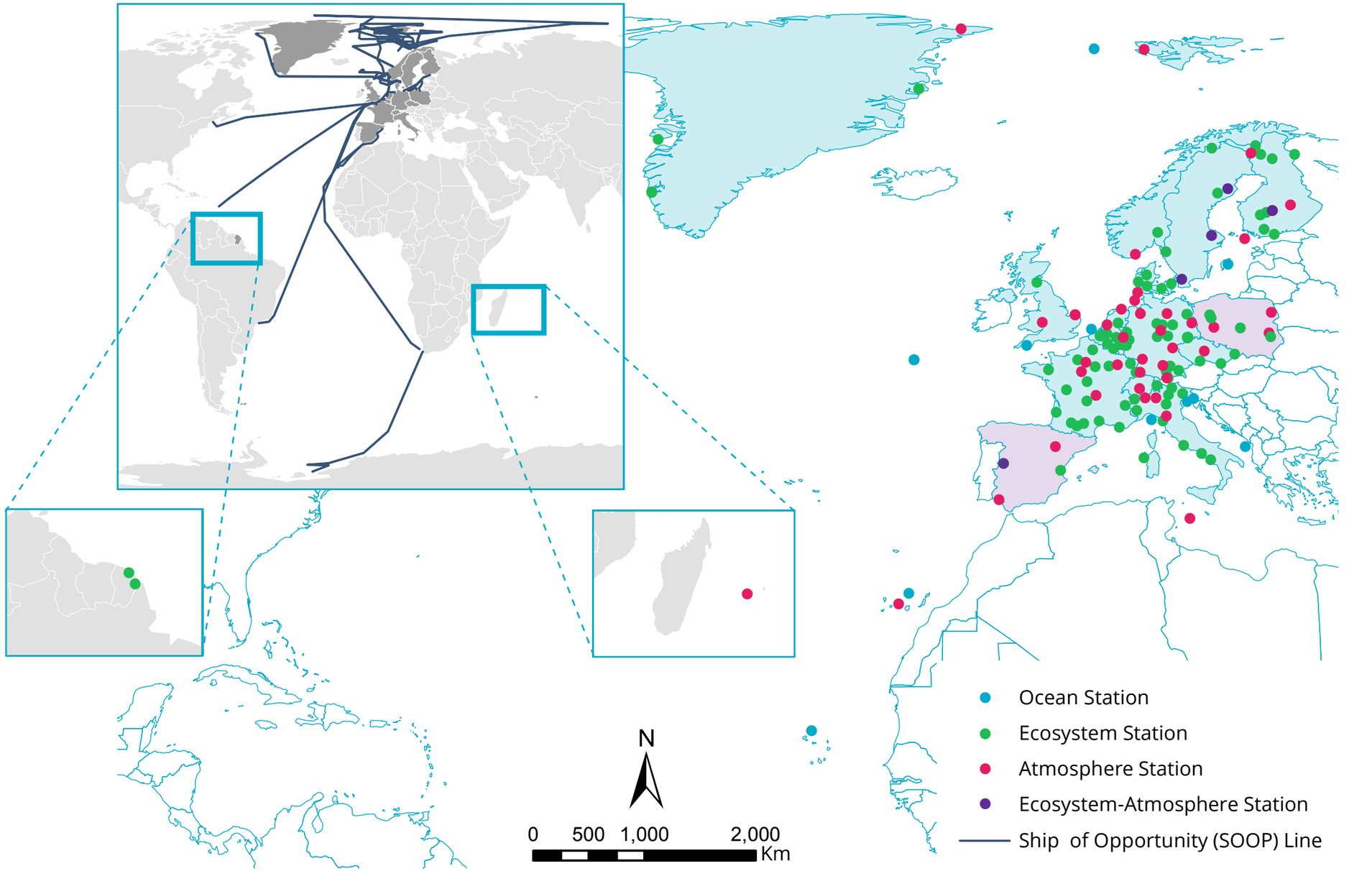
This is the second edition of the ICOS Handbook, published in 2020. In this regard, I want to thank the ICOS National Networks for their support in compiling the handbook, as well as the personnel in the Thematic Centres, Carbon Portal and in the Head Office for their efforts in producing this book. 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

WERNER KUTSCH
Director General, ICOS ERIC

ICOS Station Network

In the map, light blue indicates current ICOS countries and light violet indicates prospective countries joining ICOS in 2020.



ICOS – Standardised greenhouse gas observations throughout Europe

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

Benefits of being a part of ICOS

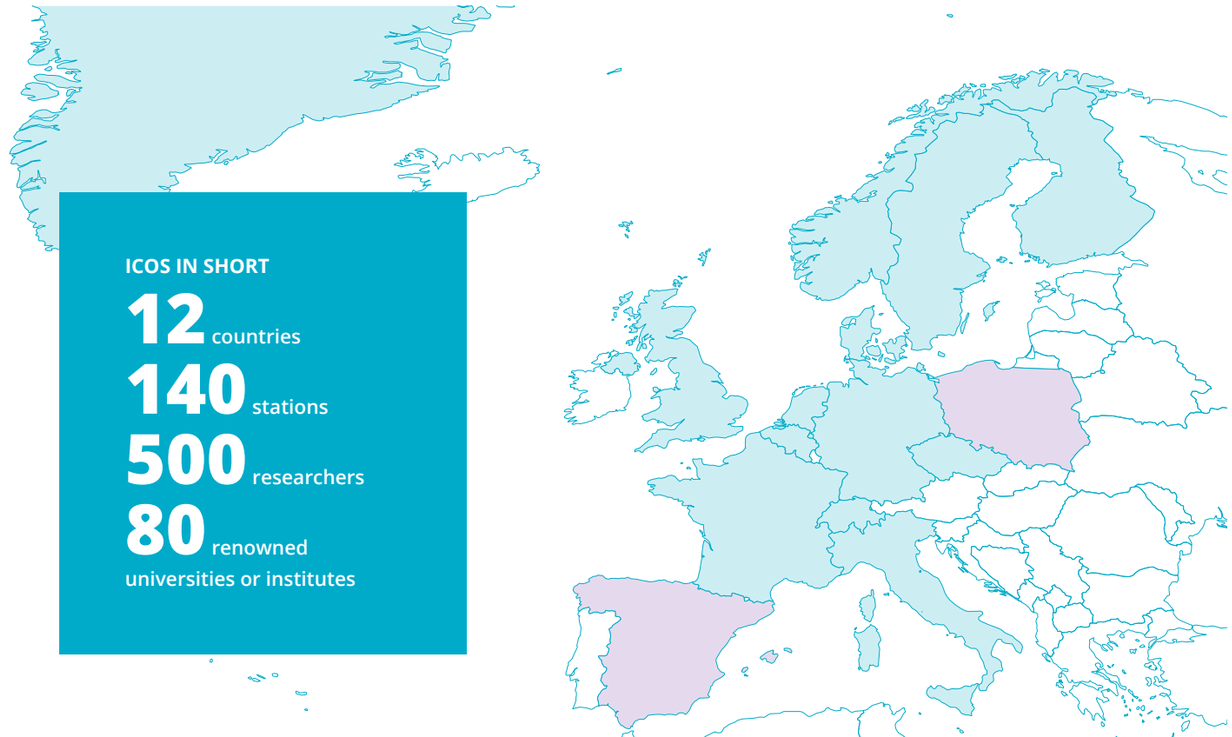
1 ICOS represents a community of scientists distributed over Europe.

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

3 We are well connected to European and global networks.

4 We promote the standardisation and curation of data.

5 We support our members who apply for funding in multi-disciplinary consortium projects.



ICOS IN SHORT

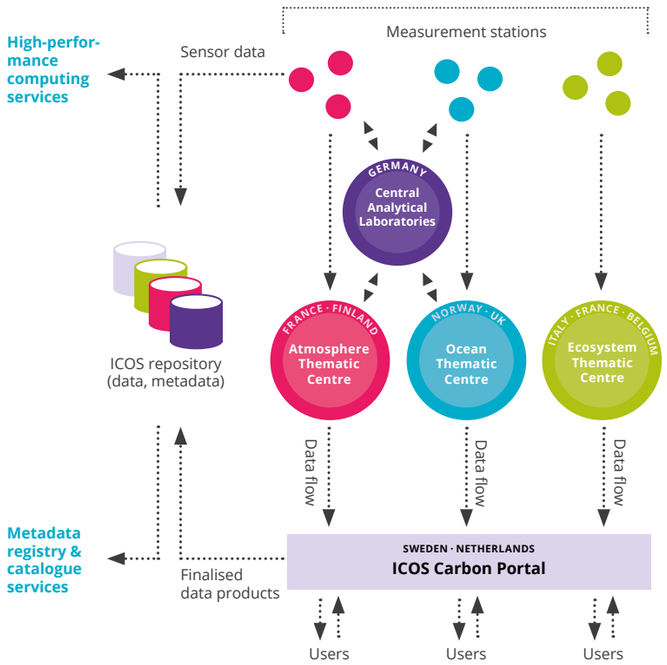
12 countries

140 stations

500 researchers

80 renowned universities or institutes

We produce high-quality greenhouse gas data open for all



Station labelling process ensures common ICOS standards and the data quality

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

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

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

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

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

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

The 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 140 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 Member and Observer countries and beyond. More than 80 renowned universities or institutes are a part of the ICOS community. The ICOS community has strong connections to colleagues and operators outside ICOS.

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

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

ICOS has also formed deep connections to global data-integration efforts. ICOS' ecosystem flux data, for example, are well connected to FLUXNET, a global network of micrometeorological tower sites. Ocean data in turn are connected to the Surface Ocean CO_2 Atlas (SOCAT) and Global Ocean Data Analysis Project (GLODAP). Atmospheric data are connected to the 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 further scientific excellence cost-efficiently. ICOS has been established to ensure high-quality measurements of greenhouse gas concentrations and fluxes that are independent, transparent and reliable. In turn, this observational network will support governments in their efforts to mitigate climate change as well as hold them accountable for reaching their mitigation targets. ICOS Member and Observer countries receive support for their national inventories and capacity building. ICOS opens new opportunities for its Members and Observers to be connected with the European and global community of researchers.

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

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

Strengthening of scientific communities

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

Advancing the standardisation and curation of data

ICOS has developed a broad range of standardisation protocols in order to ensure the highest observational standards for each ICOS station. One component of this standardisation for ICOS Atmosphere measurements is that the stations are centrally served with reference gases. The protocols are implemented during the ICOS station labelling process (described in detail in Chapter 2). This guarantees that all ICOS stations collect data that meet the agreed-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

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

Funding opportunities

ICOS supports its partners to apply for multi-disciplinary consortium projects by providing timely information on the financial and administrative process as well as on 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 GAW. During the past years, ICOS has become a respected and active participant in the advocacy work of climate change policy and management carried out in international organisations, such as the SBSTA of the UNFCCC. In 2019, ICOS became an observing Intergovernmental Organization to UNFCCC and organised its first official side-event at the COP25 meeting in Madrid.

Technology and innovation

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

ICOS' mission

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

ICOS' vision for 2025 and beyond

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

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

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

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

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

Organisational structure

The basis of ICOS' operations is the measurement network that comprises more than 140 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 standardisation of data archiving, data formats and processing methods. The Central Facilities are hosted by universities or research institutions in the Member countries.

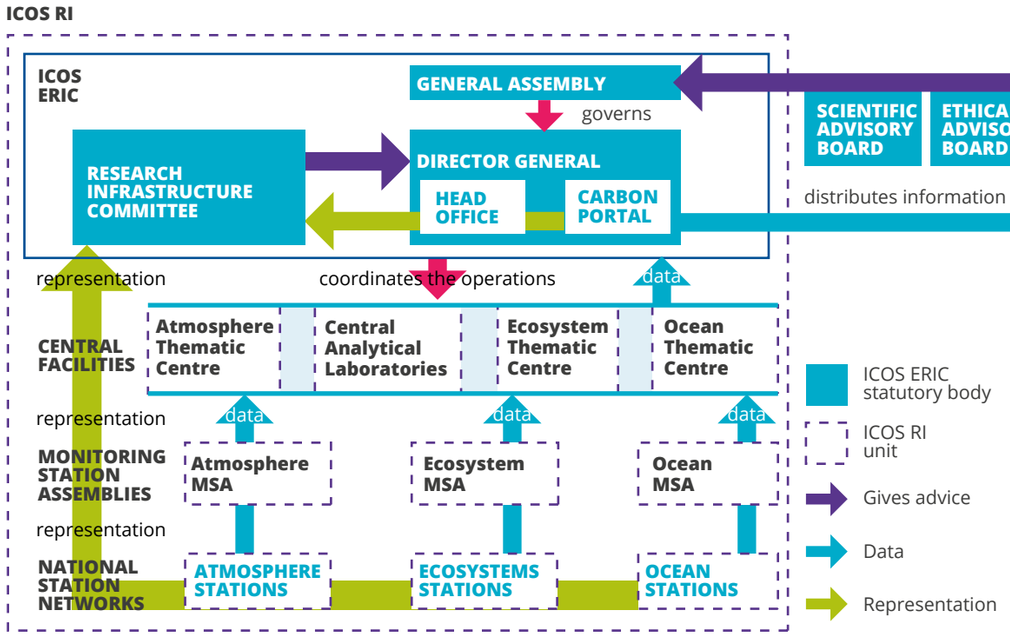
ICOS operations are coordinated by ICOS ERIC, which is a specific legal entity for European RIs created by the European Commission. ICOS ERIC consists of the Head Office, coordinating the RI operations, and the Carbon Portal, collecting and distributing ICOS data and derived products. In addition to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

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

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

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

Figure 1. ICOS RI governance and structure.



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

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

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

ICOS RI financial principles and membership contributions

ICOS' financial structure follows the general policy of ESFRI: The RIs receive stable and sustainable 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

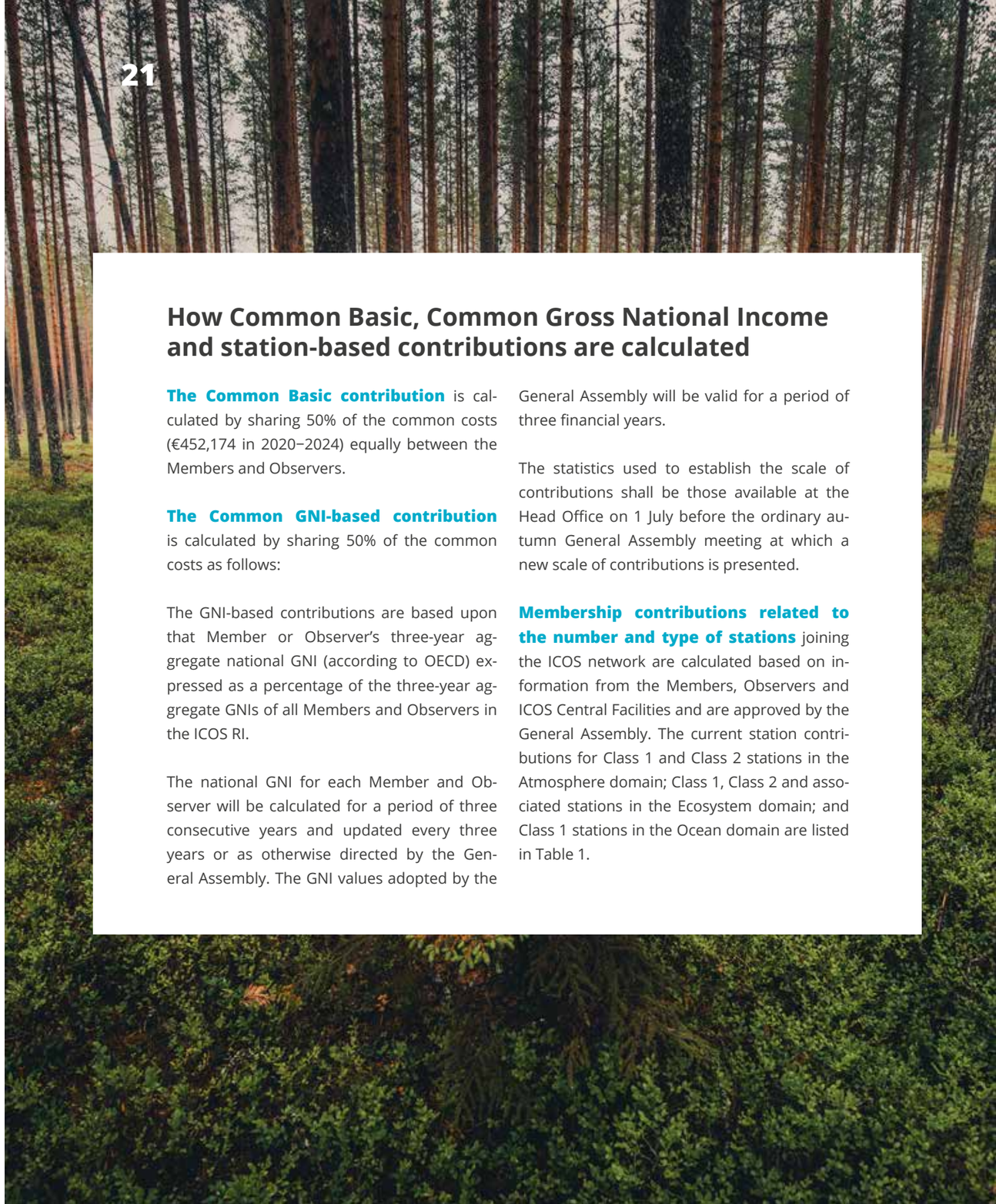
Annual membership contributions to ICOS ERIC, as well as host premium contributions by the hosting countries, cover activities that are of general benefit to the whole ICOS RI community: users, Members and Observers. ICOS ERIC statutes and the Internal Financial Rules of the ICOS RI set the principles 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 second five-year period of operations. The General Assembly has decided the Common basic and Station-based contributions for the whole five-year period 2020–2024. The amounts are shown in Table 1.

The annual budget of ICOS ERIC 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



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 (€452,174 in 2020–2024) 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 OECD) 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.

the countries hosting the Head Office (Finland and France) and the Carbon Portal (Sweden and the Netherlands). The level of Host Premium contributions for the second five-year period of ICOS ERIC can be seen in the Table 2, in the column of budget estimate 2020.

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

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

STATION TYPE	ANNUAL STATION CONTRIBUTION, €
Atmosphere Class 1	32,795
Atmosphere Class 2	11,990
Ecosystem Class 1	6,320
Ecosystem Class 2	3,160
Ecosystem associated	1,580
Ocean stations	9,650

Table 2. ICOS ERIC revenue and expenditure structure for 2017–2020, the 2020 numbers are a budget estimate approved in the GA meeting.

REVENUE K€	2017	2018	2019	2020e
Common basic contribution	219	199	226	216
Common GNI based contribution	206	206	232	206
Station based contribution to the Central Facilities	1,032	1,105	1,234	1,105
Host premium contribution (Head Office)	938	784	996	950
Host premium contribution (Carbon Portal)	677	690	791	768
Other ICOS ERIC (incl. projects, science conference)	535	1,145	1,136	914
TOTAL	**3,607**	**4,129**	**4,615**	**4,159**
EXPENDITURE K€	**2017**	**2018**	**2019**	**2020e**
Head Office activities (incl. projects, science conference)	1,210	1,961	2,149	1,915
Carbon Portal activities (incl. projects, etc.)	1,053	1,188	1,349	1,508
Central Facilities (CFs) activities	1,032	1,105	1,234	1,105
TOTAL	**3,295**	**4,254**	**4,732**	**4,529**
RESULT	**312**	**-126**	**-117**	**-370**

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

Steps towards ICOS station labelling

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

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

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

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

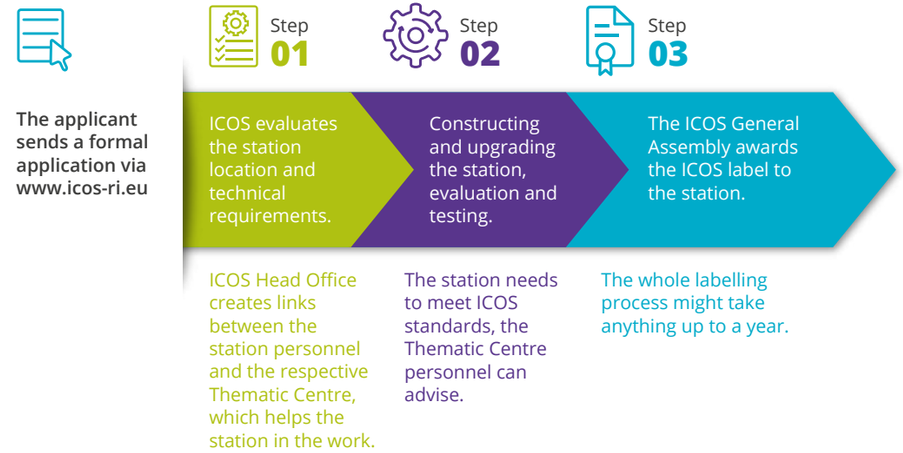
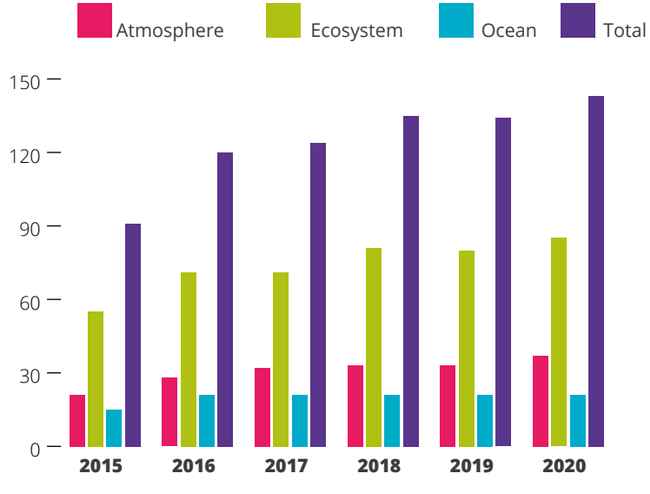


Figure 3. Number of ICOS stations in 2015–2020. The total number of stations was 144 in 2020.



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 140 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 June 2020, 58 stations had received an ICOS label.

3 ICOS DATA: How they are produced and managed

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

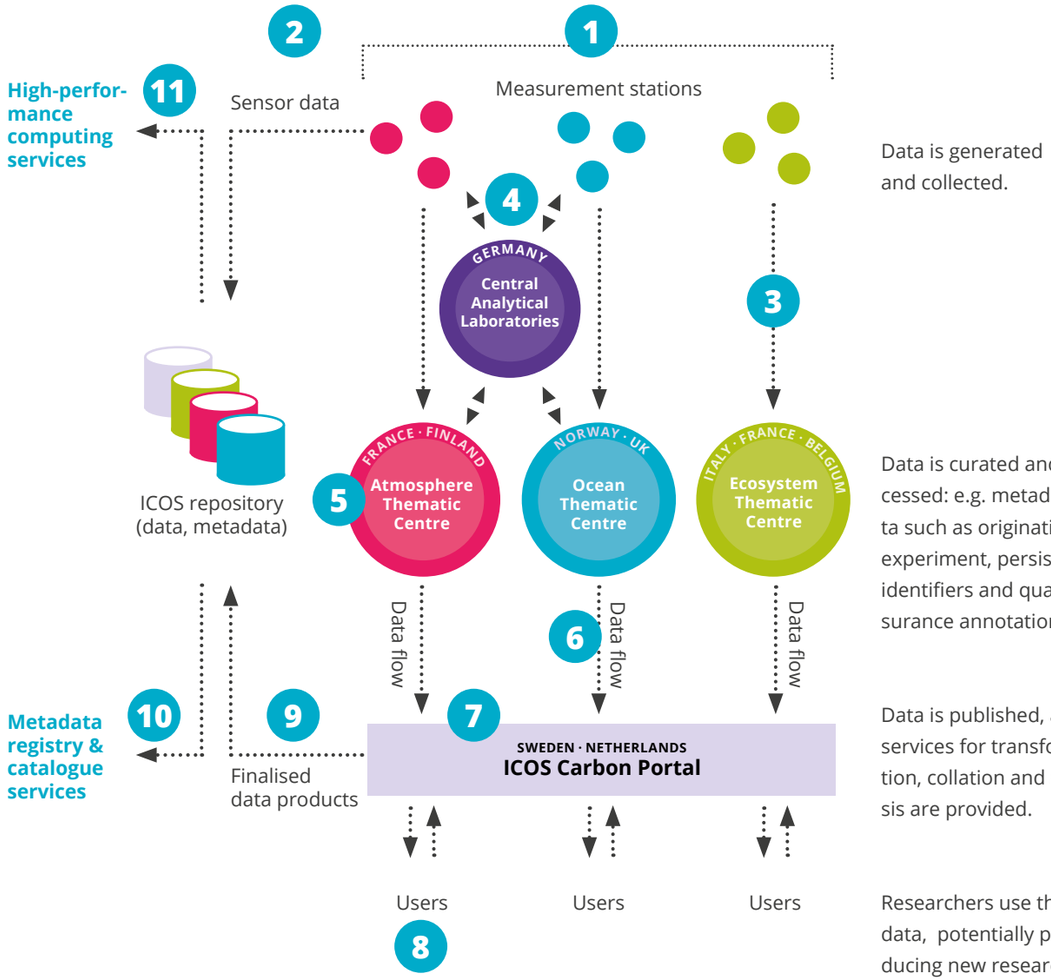
The following schematic diagram (Figure 4) shows the standardised ways of handling data within ICOS.

1. Data are collected at ICOS measurement stations. There are more than 140 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) are a part of the ICOS Central Facilities. CAL consists of Flask and Calibration Laboratory and the Central Radiocarbon Laboratory. They provide gas analyses and calibration gases.

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

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

7. The Carbon Portal is responsible for organising and taking care of all ICOS datasets. The Carbon Portal is the 'one-stop shop' for ICOS data products and offers advanced search, visualisation and downloading services. The portal is also responsible for all ICOS data management (such as assigning identifiers, DOIs, to make them easily cited), for tracking how ICOS data are used and for long-term archiving. Finally, it 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, coastal and mountain stations where data on greenhouse gas concentrations in the atmosphere are collected. The ICOS Atmosphere network covers a large part of the European continent. The data feed, for example, informs inverse modelling approaches describing the sources and sinks of greenhouse gases.

How an Atmosphere station operates

Each ICOS Atmosphere station is an observatory established to continuously measure the dynamics in the concentration of greenhouse gases (CO_2, CH_4) and other trace gases (for example, CO), which are the result of regional and global 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, N_2O), or the replacement of the existing instruments with more advanced ones at a later date may occur. The mandatory parameters that each category of station in the ICOS Atmosphere network measures are listed in Table 3. The requirements for data quality and compatibility are the same for ICOS Class 1 and Class 2 stations.

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

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

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

Table 4. Estimated equipment cost (k€) for the ICOS Atmosphere station

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 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

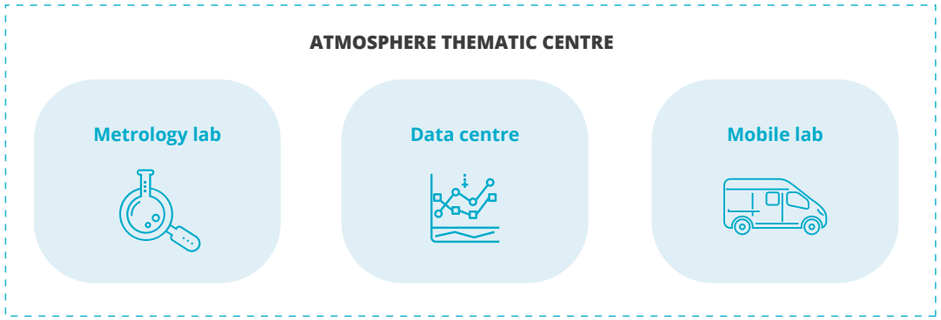
The ICOS Atmosphere observations are coordinated by the ATC in close cooperation with the Atmosphere Monitoring Station Assembly and Central Analytical Laboratories. The ATC is composed of a data centre and a metrology lab and is complemented by an in situ station quality-control mobile lab (Figure 5). 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 (person month, PM) for the operation of an ICOS Atmosphere station

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

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

Figure 5. Structure of the ICOS Atmosphere Thematic Centre.



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

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

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

The CRL quantifies the radiocarbon (^{14}C) content of CO_2 in air samples and develops methods to de-rive 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
- Gas chromatograph (Agilent 7890A) for CO_2, CH_4, N_2O, H_2, CO and SF_6 concentration analyses in flask samples (detector types: FID, ECD, PDD, RGD)
- Oil-free compressor (Rix) combined with a Zero Air Generator and a depletion/spiking system for selective adjustment of tracers to produce real air calibration gases
- Cavity ringdown spectrometer (Picarro G2301) for CO_2 and CH_4 measurements
- Off-Axis Integrated Cavity Output Spectroscopy spectrometer (Los Gatos) N_2O/CO analyser
- FTIR Spectrometer (Ecotech Spectronus FTIR) for CO_2, N_2O, CO and CH_4 analyses
- ^{14}C low-level gas proportional counting facilities for high-volume samples
- Semi-automated CO_2 extraction and graphitisation devices to produce graphite targets for subsequent AMS analysis

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

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

Interoperability among Central Analytical Laboratories, Thematic Centres and Observation networks

Sample logistics

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

Data processing

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

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 standardised protocols developed for field ecosystem measurements.

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

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

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

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

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

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

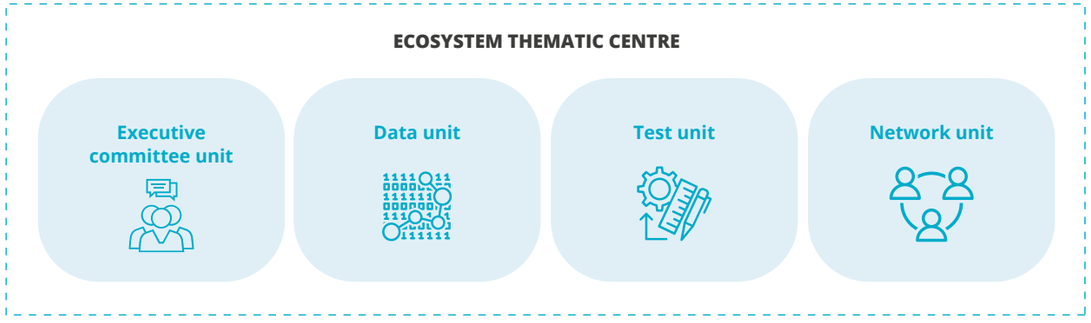
Table 8. Estimated equipment cost (k€) for the ICOS Ecosystem station

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.



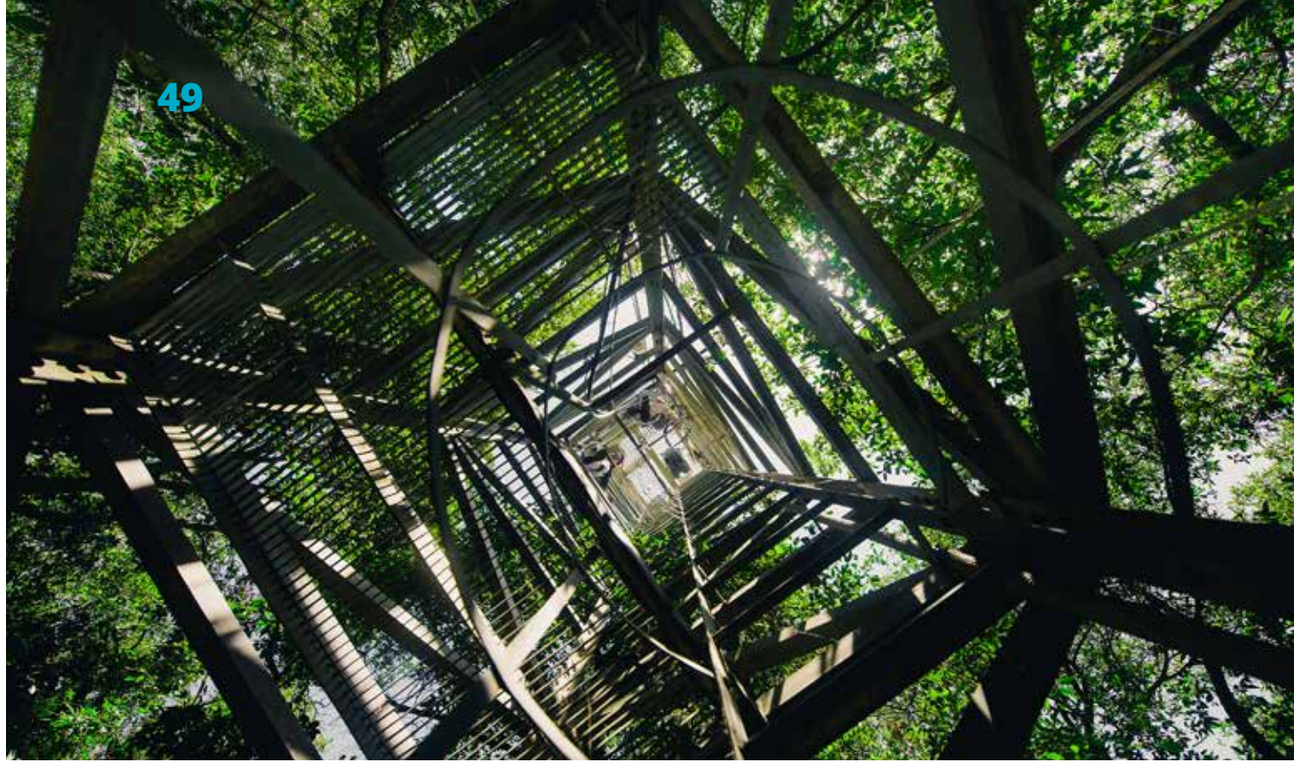
Ecosystem Thematic Centre: Coordinating observations and processing data

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

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

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

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



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

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

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

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

Ocean observations

ICOS provides long-term observations from 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 Ships of Opportunity (SOOP). They all have been equipped with state-of-the-art carbonate system sensors.

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

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

How an ocean station operates

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

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

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

SOOP and MFT typically measure semi-continuously, while the temporal coverage of FOS ranges from semi-continuous to annual. For each category of Ocean stations, ICOS defines two classes of stations according to the set of parameters measured (see 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 SOOP stations.

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

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

Table 11b. List of required variables measured at ICOS FOS stations with continuous/quasi-continuous measurements.

VARIABLE	FREQUENCY	ACCURACY	REQUIRED FOR CLASS
Sea surface pCO_2	> 1/day (open ocean) > 3/day (coastal)	± 10 µatm	2
Sea surface temperature	> 1/day (open ocean) > 3/day (coastal)	± 0.02 °C	2
Sea surface salinity	> 1/day (open ocean) > 3/day (coastal)	± 0.1 PSU	2
Pressure (depth)	> 1/day (open ocean) > 3/day (coastal)	± 3 dbar	2
Dissolved oxygen	> 1/day (open ocean) > 3/day (coastal)	± 2%	2
Total alkalinity (TA)*	**	± 4 µmol kg^{-1}	2
Dissolved inorganic carbon (DIC)*	**	± 2 µmol kg^{-1}	2
pH***	**	± 0.003	2
Dissolved nutrients ****	**	± 1-3%****	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.
*** pH (together with TA or DIC) is ONLY required for validation of the pCO_2 data. pH should NOT be used together with pCO_2 to calculate the full carbonate system due to high resulting uncertainty.
**** At least two out of the three dissolved nutrients nitrate (NO_3), phosphate (PO_4), and silicate ($Si(OH)_4$) must be provided.
***** The accuracy refers to samples without conservation. If conservation is used (freezing is the most used method) the accuracy might increase.

The current Ocean station setup consists of 11 SOOP 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.

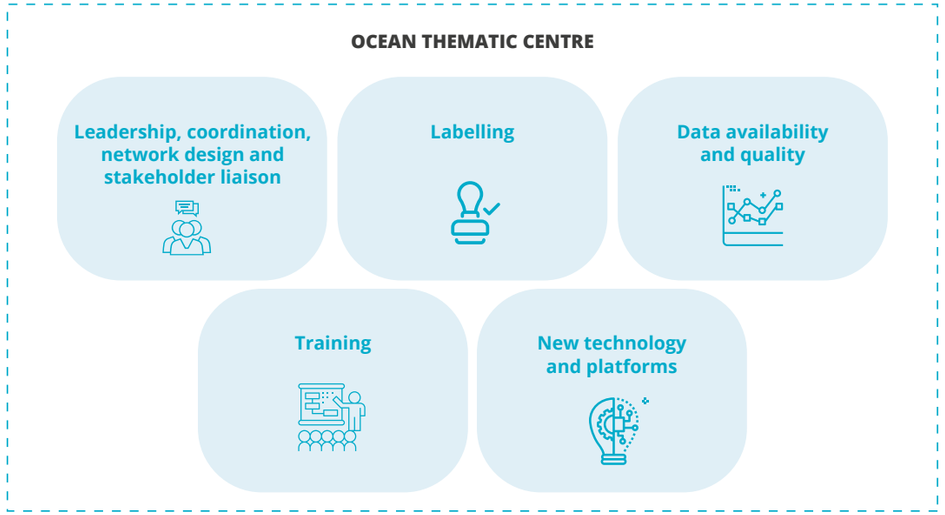


Figure 7. Structure of the ICOS Ocean Thematic Centre.

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

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

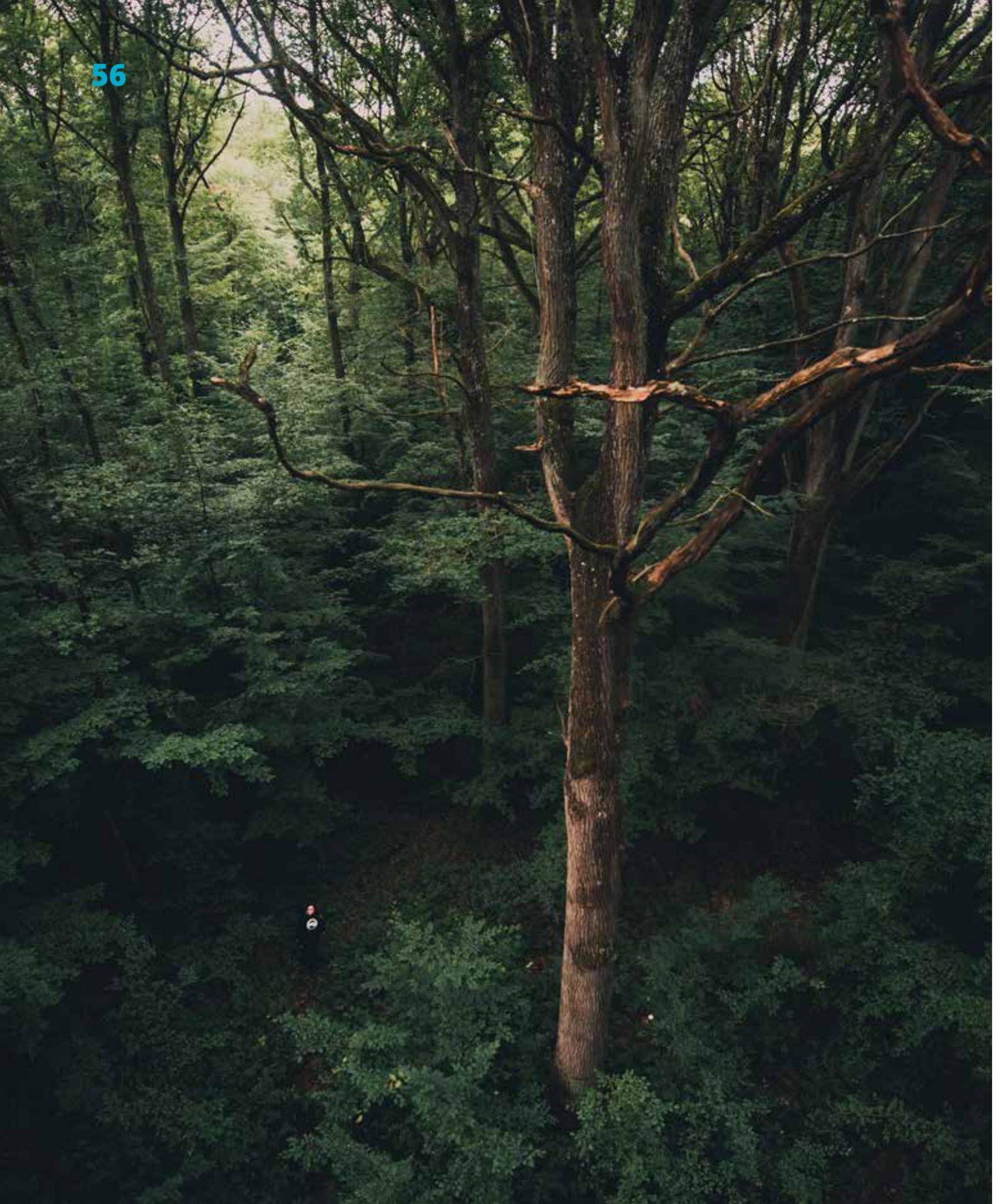
New Technology and Platforms Unit is in charge of new sensors and new platforms. Its task is to invite early adopters as collaborators or partners in future research grants to explore new technologies.

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

CATEGORIES	DESCRIPTION	SOOP		FOS		
		Class 1	Class 2	Class 1	Class 2	Flux tower
CO_2 in situ measurements	UW equilibrator based system	100	100			
CO_2 in situ measurements	Membrane based system			35	35	
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	SOOP		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 standardised data-exchange protocols and techniques. Organising the long-term archiving of ICOS data products, with the aim of guaranteeing their safe storage and future access (including after a possible cessation of the research infrastructure itself), is an important task of the Carbon Portal. The Carbon Portal's activities and features are as follows:

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

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

Data mining, data extraction, collocation

In order to facilitate the interactions of a wide spectrum of user categories, the Carbon Portal acts as the main access platform for any and all parties interested in ICOS data products. In addition, the Thematic Centres may operate their own data-access interfaces, provided authentication control is given through the Carbon Portal. The web design, data traceability and download and usage statistics as well as the enforcement of the ICOS data policy of such Thematic Centre interfaces are closely coordinated by the Carbon Portal. The Carbon Portal develops efficient search capabilities that allow users to locate and retrieve data of interest, 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 for users

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

IT services for the ICOS community

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

NextCloud Fileshare: document sharing & editing in the cloud. A cloud-based service to store and share your documents (text, spreadsheets, presentations, any data file) with colleagues. The fileshare offers a cooperative document editor like Google Docs (highly compatible with MS Office), so that you can work with many persons simultaneously on manuscripts, data and presentations, with guaranteed privacy. We assign you the permissions to the right group shares when you register. Beware that processing your registration can take a few working days.
Main link: fileshare.icos-cp.eu
Further info and help: bit.ly/2Vp6oVk

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

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

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

Head Office

The Head Office (HO) is the organisational hub of the entire ICOS RI. It supports and connects all constitutional bodies of ICOS European Research Infrastructure Consortium (ICOS ERIC). The Head Office prepares the meetings of the overall governing body, the General Assembly (GA), and implements its decisions. The HO prepares and monitors the annual work plans and budgets, and oversees implementation and updates of ICOS strategy. The HO coordinates the operations of ICOS RI in close cooperation with the Research Infrastructure Committee (RI COM) which has representatives from other bodies of the RI. The Head Office is led by the Director General (DG). DG and the HO have developed a broad network for international cooperation and effective communication, including videos and exhibitions during the past years and will even increase these efforts in the future.

The Head Office works together with the Central Facilities to coordinate overall activities and develop the ICOS RI. The activities and deliverables 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 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. Further, the Head Office coordinates and facilitates future network development and extension in cooperation with the ICOS Central Facilities and Monitoring Station Assemblies.

The administrative areas 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 raise awareness and perceived value of ICOS and its data products among key external stakeholders and to strengthen the sense of belonging among its own community. Educating the general public about importance and methods of greenhouse gas measurement is also within its scope. Actions taken to reach these goals include 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.
The amount of work needed in the areas described above has varied depending on the phase ICOS RI has been in its life cycle. In the beginning, community building and design needed much efforts, then construction and now operation. In the future, potential expansion will need extra resources. Consequently, the number of personnel in the Head Office, and the funding of the tasks have developed throughout the ICOS RI life cycle, with project funding providing the important extra resources for the development. In the future, we expect that basic funding will cover the resources needed, while potential projects will continue to fund and develop ICOS RI in the future.

Head Office tasks

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

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

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

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

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 preliminary Key Performance Indicators (KPIs) as well as methods to measure them. ICOS has continued to develop methods to measure its impact, for example, within its development project RINGO, and taking account the KPI work carried out in ESFRI, European Research Infrastructure Forum.

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.

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

A DOI-minting process done by ICOS Carbon Portal database shows that ICOS-originated papers (Figure 8) have the potential to be widely cited (Figure 9). The DOIs are a rather new development in data use, and thus not yet as widely used as ICOS would hope for.

From the figures, however, it is evident that the publication and citation trends of ICOS data go strongly upwards, demonstrating the increasing use of ICOS data in science. In addition, possibly because

of the breadth of ICOS' coverage of oceanic, atmospheric and land-based observations, ICOS-originated publications cover a large number (189) 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.

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

ICOS' impact is also amplified by its role as the analytics and synthesis service provider for the wider scientific community. ICOS is the main European provider to the 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.

ICOS' socio-economic 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 manage to reduce the climate change sufficiently due to in-

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

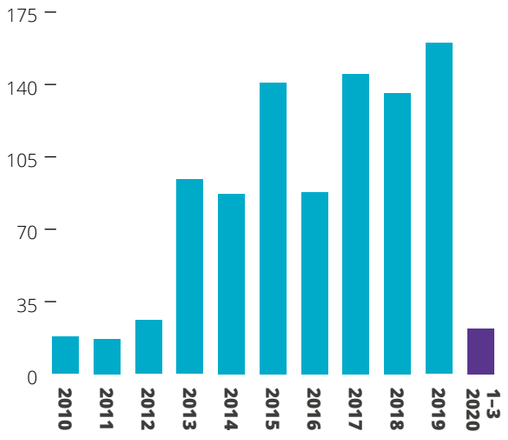
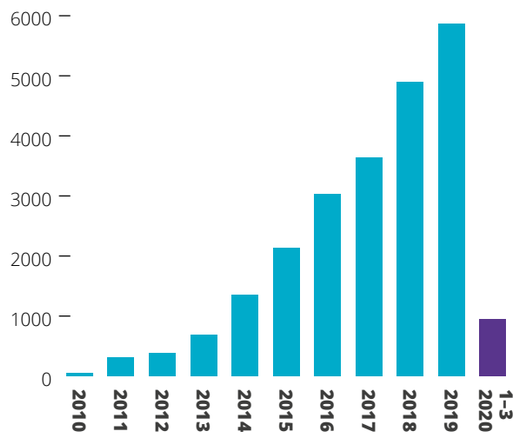


Figure 9. Citations of ICOS-related publications, 2010–2020.



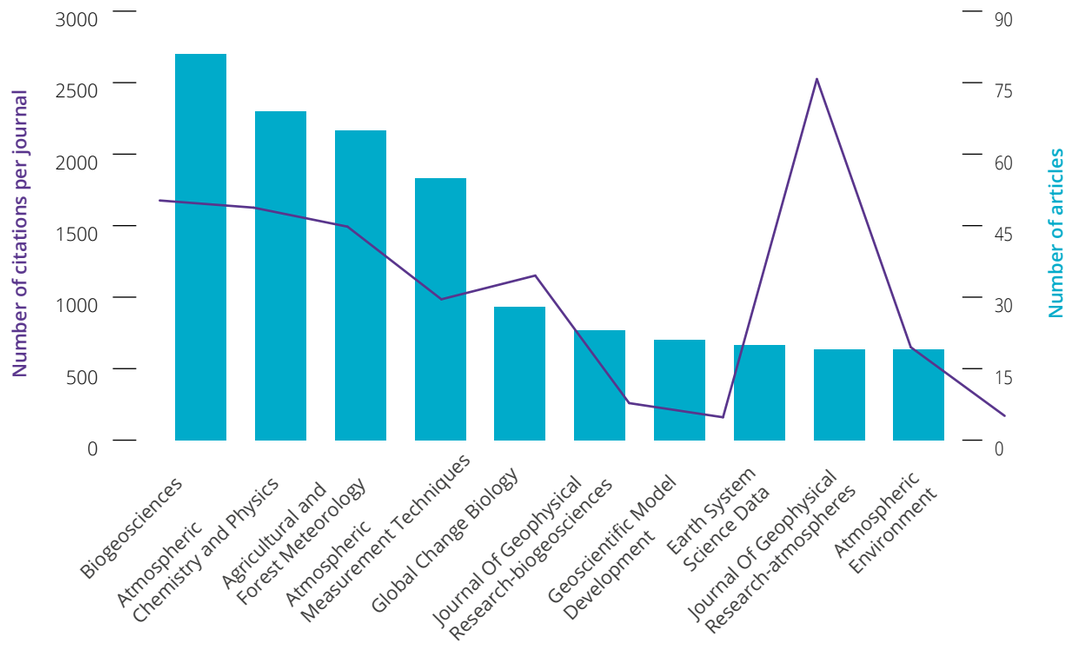
adequate actions, the global warming will lead to extremely large societal costs caused by adaptation efforts, losses and damages. Compared to the values at risk, the investments and running costs needed for a global greenhouse gas monitoring and analysis network are marginal and would easily provide return due to the improved effectiveness of the science-guided mitigation strategies.

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

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 UNFCCC is the global framework in which greenhouse gas emissions are monitored, and action is implemented to reduce them. The Global Climate Observing System (GCOS) defines the essential cli-

Figure 10. The top 10 journals in which ICOS articles have been published and the number of articles and citations in these journals.



mate variables that must be systematically observed. Together with the World Meteorological Organization (WMO) and its Integrated Global Greenhouse Information System (IG3IS), ICOS provides the necessary data on the situation of greenhouse gas concentrations and fluxes in Europe. In the interviews conducted for the ICOS Impact Assessment, WMO officials mention that the measurement standards of ICOS are the best available in the world and that ICOS data are the core of global GHG inventories.

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

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

Several parts of the ICOS RI provide their expert contribution to the Copernicus in situ coordination project led by the European Environment Agency. ICOS is represented by the Carbon Portal, and the ATC and CRL provide their expertise, for example, in $^{14}CO_2$ observations for fossil-fuel CO_2 estimates. The ATC participates in the Copernicus Atmosphere Monitoring Service (CAMS) project of the European Union's Earth Observation Programme, which aims to consolidate and improve the preparation, transmission and quality control of near-real-time ICOS atmosphere data for the benefit of ICOS and other users. The data in the Copernicus service will be utilised, for example, by national weather services or private companies to improve air-pollution predictions and also to develop other data products based on ICOS data, such as maps of fossil-fuel emissions.

Finally, ICOS has a unifying 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 research- 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

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

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

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

Other campaigns include, for example, 'CO2FFFEE with ICOS' videos published in YouTube in 2020. In these, scientists discuss with Fridays for Future youths, giving in-depth information about climate change.

In additional to the ICOS ERIC, National Networks and Central Facilities actively promote the importance of greenhouse gas research. They have participated in local or national science days and climate events, produced educational materials and worked together with ICOS HO to achieve publicity for their results in the main media.

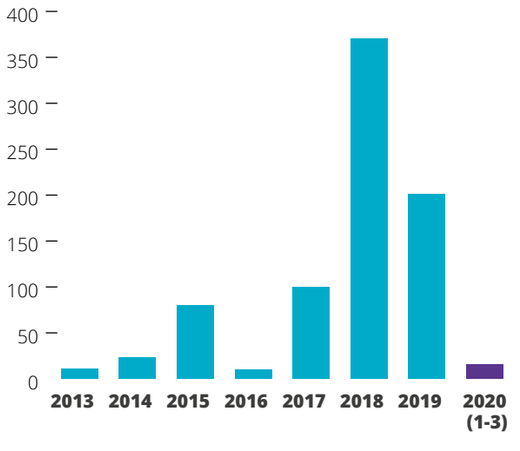
The number of general media articles concerning the ICOS RI has been around 120 annually since 2013 (Figure 11). The ICOS website was renewed in 2020 to merge ICOS RI and Carbon Portal websites. The renewed website offers targeted tools and information for scientists, policy-makers, as well as to media and educators.

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 all domains. The ATC metrology lab has built collaborations with industrial companies to test emerging technologies. Innovative ICOS ATC software is used by ICOS Principal Investigators for quality control and for station network management systems. The ETC and Carbon Portal cooperated with private companies in the development of a specific logger for the automatic data-submission process. The OTC has partnered with a private company to validate the ICOS ocean data from fixed ocean stations using a wind-powered, fully autonomous ocean drone (Saildrone). OTC is also engaging instrument suppliers to an inter-comparison campaign to reach a high level of standardisation. 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 2013–2020.



6 HOW TO BECOME AN ICOS ERIC MEMBER OR OBSERVER

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

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

ICOS ERIC Members currently include Belgium, the Czech Republic, Denmark, Finland, France, Germany, 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 a 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 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 contact person 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.

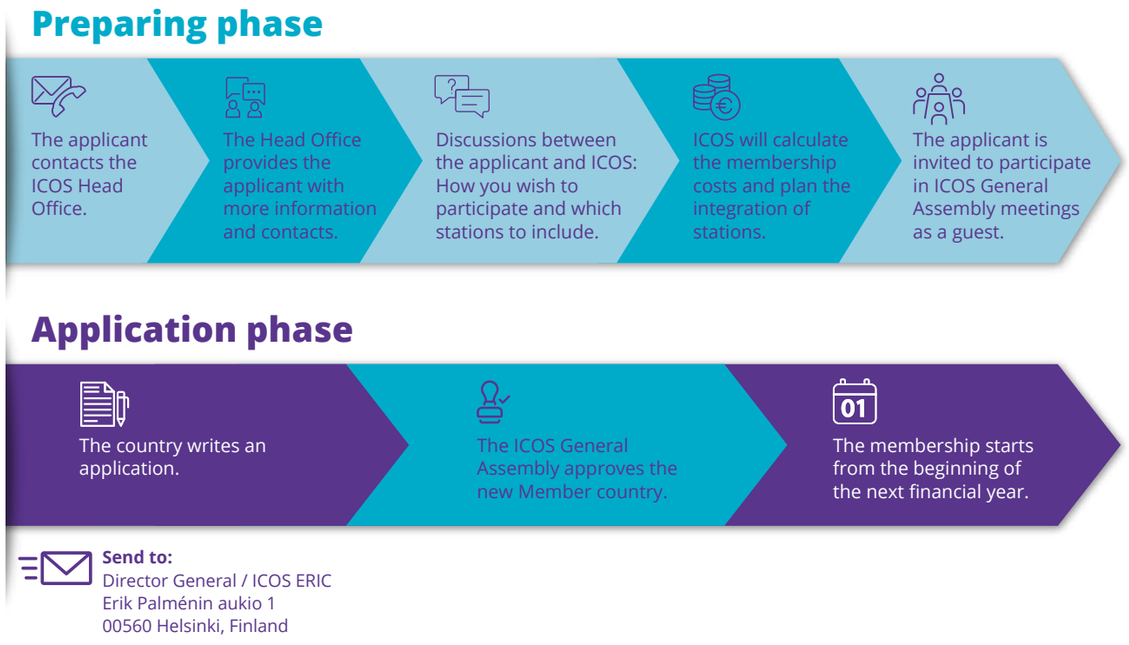
The application should also include a statement that the applicant fulfils the Membership obligations stated in the ICOS ERIC statutes, Article 6(2).

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).

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.

Figure 12. Steps towards ICOS membership.



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.

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 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 contact person 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 144 (in May 2020) 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.

The station network maps in the following pages are illustrations and rather simple snapshots of the network in 2020. For up-to-date and more detailed maps with adjustable layers, please visit www.icos-ri.eu.

ICOS Belgium

ICOS BELGIUM FOCAL POINT
Ivan Janssens
Professor
Plants and Ecosystems, PLECO
University of Antwerp, Belgium

contact-belgium@lists.icos-ri.eu
+32 3 265 22 55
www.icos-belgium.be

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

The role of ICOS Belgium

Belgium hosts ten stations in total and is involved in all three observation networks. The University of Antwerp is hosting the Ecosystem Thematic Centre (ETC) together with INRAE (France) and CMCC (Italy). Despite Belgium's diverse landscape and high human density, ecosystems play an important role and the ICOS-BE network covers well the typical land-uses and economically important North Sea.

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

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

The ICOS Belgium Infrastructure

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

The Ecosystem network consists of two agricultural sites (Dorinne and Lonzée), two forest sites (Brasschaat and Vielsalm), one heathland site (Maasmechelen) and one poplar plantation site (Lochristi).

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

The Atmosphere station at Ile de La Réunion is a Belgian-French collaboration (between BIRA and the French partners of LSCE and the Université de La Réunion) performing background measurements of greenhouse gases in the Indian Ocean. The Observatoire de l'Atmosphère du Maïdo consists of two observational stations: one close to sea level and one at about 2,100 m above sea level. A new site in the Congo basin has been proposed as an Ecosystem Associated station from 2021 onwards, operated by Ghent University. Located in Yangambi in the Democratic Republic of Congo, CongoFlux will contribute to the understanding of the global carbon cycle in undersampled and critical zones.

The ICOS Belgium Funding Structure

The current ICOS Belgium Consortium involves four Walloon, three Flemish and two Federal institutes. Each institute is funded by its respective govern-

ment, while the Federal government represented by the Belgian Science Policy Office (BELSPO) carries the cost of the membership fees.

Until 2018, no structural funding existed for the involvement of the Flemish partners in ICOS, but a yearly subsidy was provided since 2012. The Research Foundation – Flanders (FWO) launched a call for structural funding for international research infrastructures in 2018 which resulted in a two-year grant for 2019–2020. The Flemish partners have applied for renewal of the grant for 2021–2024 in the 2020 FWO call. The CongoFlux station (Ghent University) is part of this new proposal.

The Walloon partners received funding in 2013 from the Service Public de Wallonie to finance three Ecosystem stations. The project, called ICOS Wallonia-Brussels, had a duration of eight years. In 2020, the Walloon partners will apply for a renewal of the project for a period of five years.

BIRA has received financial support from BELSPO through the ministerial decree for ICOS for a period of 5 years since December 2014 for running the Observatoire de l'Atmosphère du Maïdo at Ile de La Réunion. The RV Belgica, operated by RBINS-OD Nature, is funded by BELSPO via yearly renewed grants. Since the federal cabinet has not yet made a decision about the future support for European Research Infrastructures, the federal partners received an extension of the actual financial support until end of November 2020. It is expected that the future funding will be granted on the basis of competitive calls.

Figure 13a

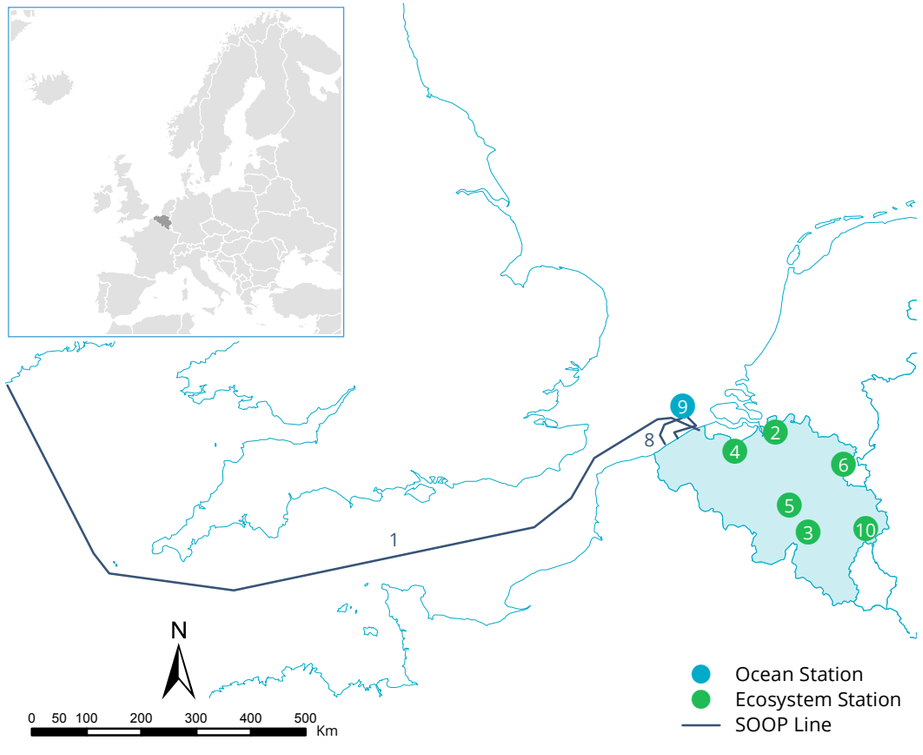


Figure 13: The ICOS Belgium station network. Figure 13a primarily covers Ecosystem and Ocean stations around mainland Belgium, while Figure 13b shows the remote Atmosphere station that is located in Ile de La Réunion in the Indian Ocean. The numbers in the maps correspond to the numbers in Table 13.

Figure 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

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

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

Université catholique de Louvain (UCLouvain)
uclouvain.be

University of Liege
www.uliege.be

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

Table 13. ICOS Stations in Belgium

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

ICOS Czech Republic

ICOS CZECH REPUBLIC FOCAL POINT

Jiří Kolman

Scientific Secretary of CzechGlobe

Czech Republic

contact-cz@list.icos-ri.eu

+420 511 192 299

www.icos-infrastructure.cz/english

Lanžhot: an Ecosystem station of ICOS Czech Republic.

The role of ICOS Czech Republic

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

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

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

The ICOS Czech Republic infrastructure

ICOS Czech Republic is hosted and operated by a single institution: CzechGlobe - Global Change Research Institute of the Czech Academy of Sciences. The Czech ICOS stations are included in the national CzeCOS project. The Czech ICOS comprises one Atmosphere station and three Ecosystem stations (Figure 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 Atmosphere station Křešín u Pacova is situated in the middle of the Czech Republic. It has been in operation since 2013 and it serves as a national monitoring point for both the occurrence and remote transmission of greenhouse gases, selected pollutants and basic meteorological characteristics. The station consists of a 250-metre-high meteorological research mast, at the various height levels of which atmospheric concentrations of greenhouse gases (CO_2, CH_4, CO, N_2O, SF_6), pollutants (tropospheric ozone, gaseous mercury and aerosols) as well as basic meteorological characteristics (air temperature, pressure and humidity, wind speed and direction) and the height of the atmosphere boundary layer are monitored.

The ICOS Czech Republic funding structure

The ICOS Czech Republic is part of the Czech national research infrastructure 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. The numbers in the map correspond to the numbers in Table 14.

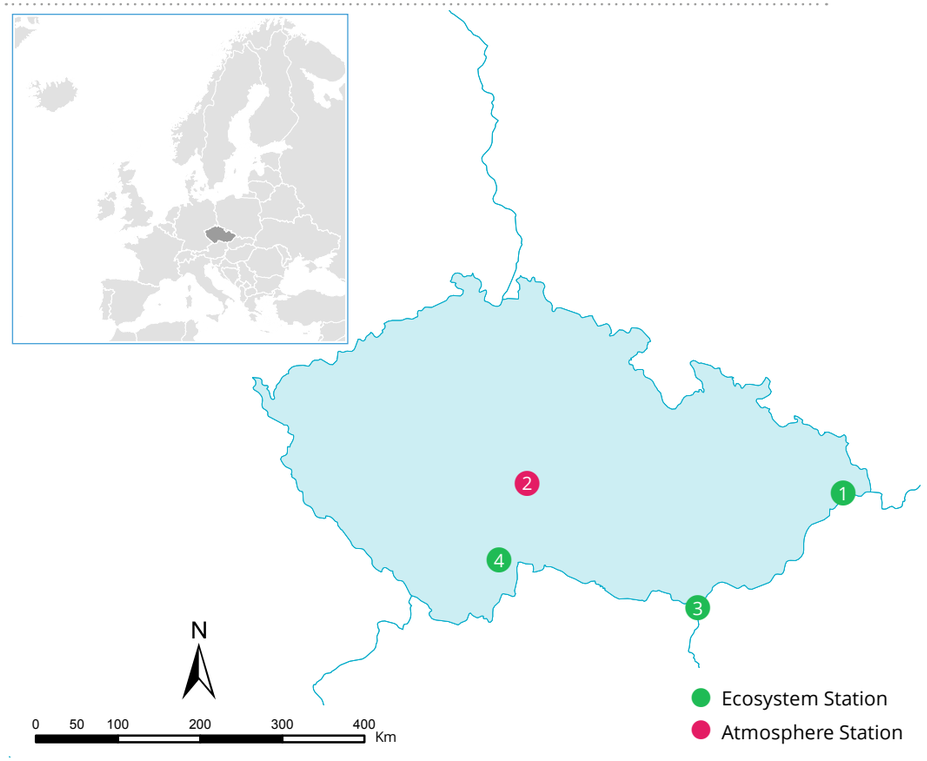


Table 14. ICOS Stations in the Czech Republic

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

ICOS Denmark

ICOS DENMARK FOCAL POINT

Kim Pilegaard

Professor

The Technical University of Denmark (DTU)

Denmark

contact-denmark@lists.icos-ri.eu

+45 4525 2158

www.icos-denmark.dk

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. The numbers in the maps correspond to the numbers in Table 15.

Figure 15a

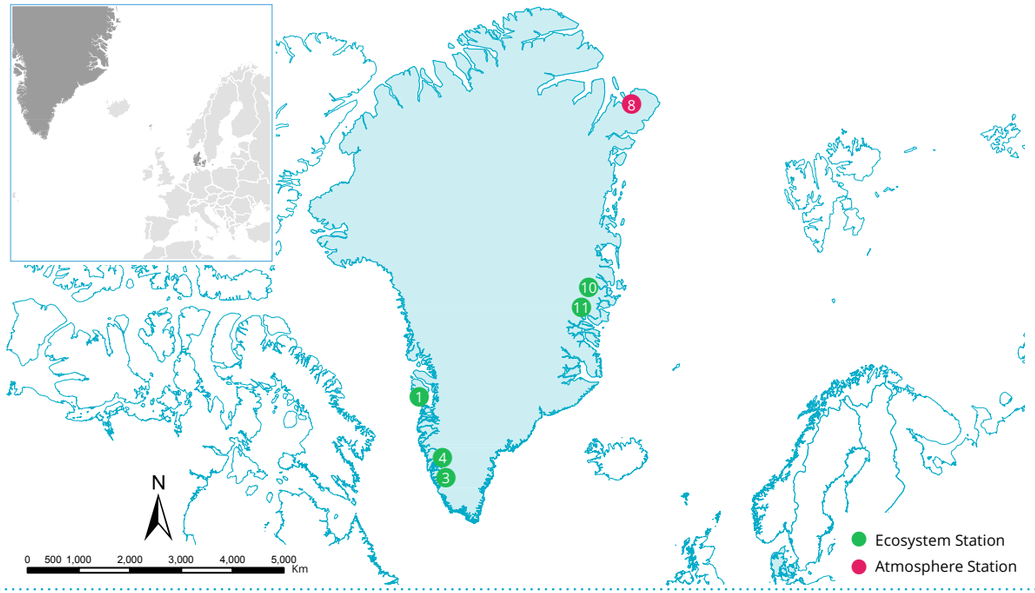


Figure 15b

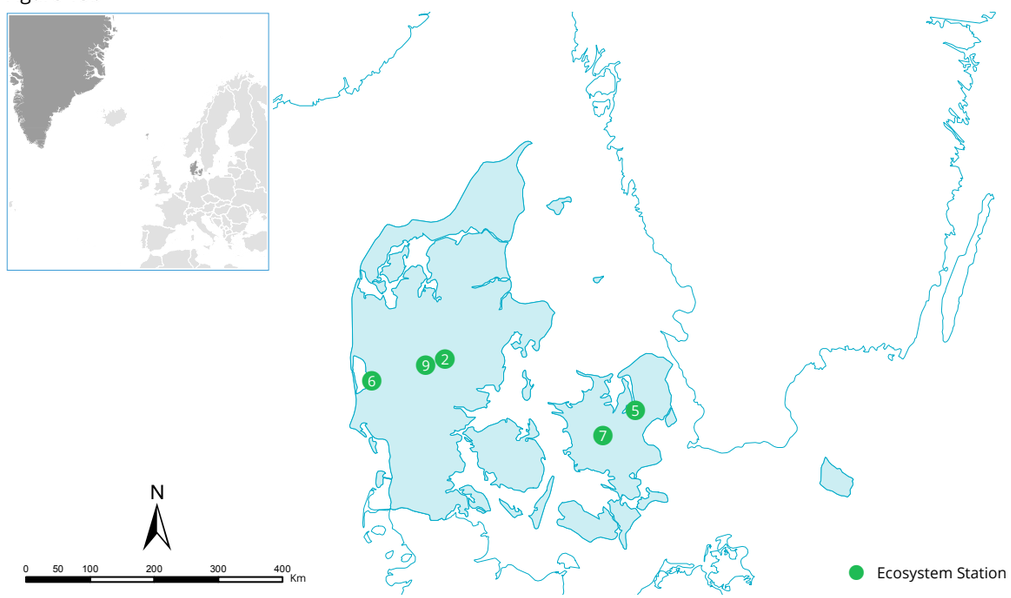


Table 15. ICOS Stations in Denmark

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

*The station is located in Greenland.

ICOS Finland

ICOS FINLAND FOCAL POINT

Annalea Lohila

Associate Professor

Institute for Atmospheric and Earth System Research (INAR), University of Helsinki and Finnish Meteorological Institute

Finland

contact-finland@lists.icos-ri.eu

+358 50 366 32 42

www.icos-finland.fi

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. ICOS Finland studies the sinks and sources of greenhouse gases in typical boreal and subarctic ecosystems, focusing on coniferous forests and peatlands but also including the unique sites of a lake and an urban environment.

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

The ICOS Finland infrastructure

The ICOS Finland network consists of thirteen stations (Figure 16; Table 16), of which four are Atmosphere stations, four Ecosystem stations, and five Associated Ecosystem stations.

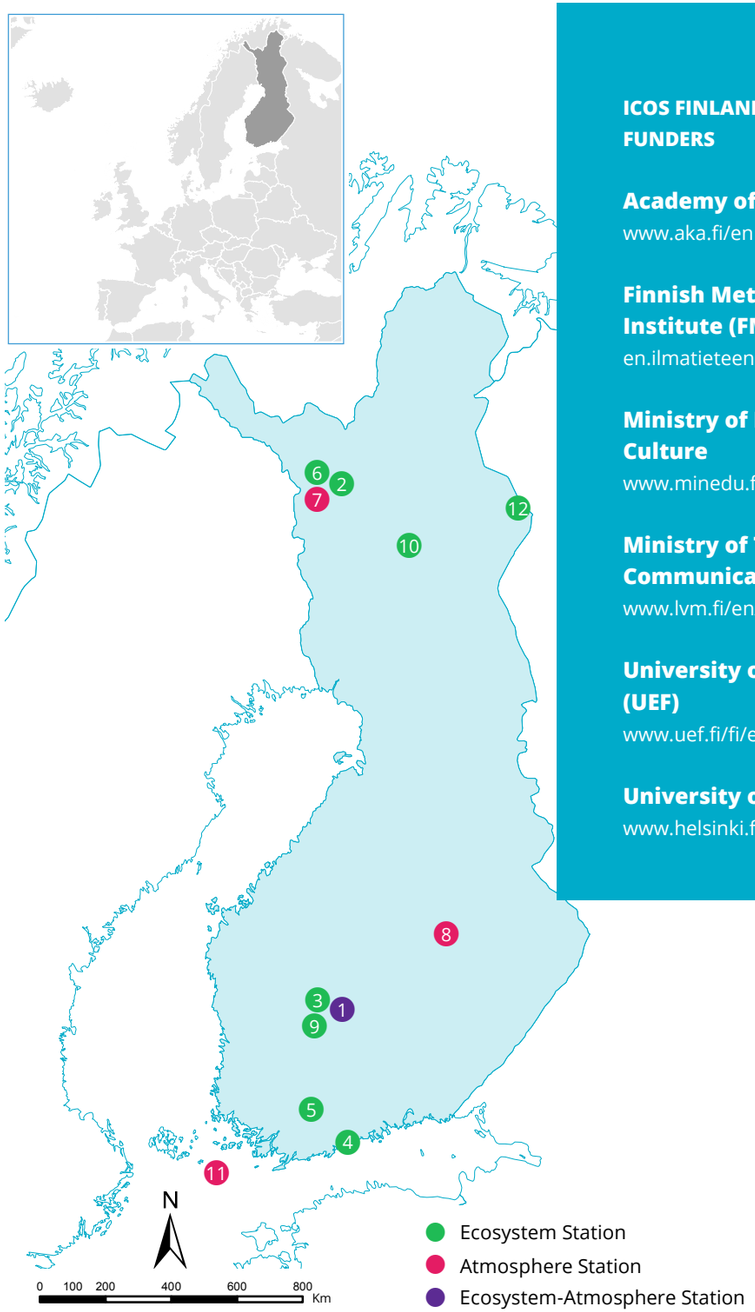
Seven of the ICOS Finland stations also belong to the SMEAR network. Four stations operated by FMI are part of the Pallas Atmosphere-Ecosystem supersite, one of these (Pallas-Sammaltunturi) belonging to the Global Atmosphere Watch (GAW) of the WMO. The GHG data from Pallas has been distributed via GAW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

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

In addition to these, data on sensible heat flux and latent heat flux (evapotranspiration), as well as those on various meteorological and ecophysiological (vegetation and soil) variables are available, together with essential metadata. During the last five years, the Hyytiälä ICOS ECO data alone has been downloaded over 2000 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

In 2010–2019, ICOS Finland partners UHEL and UEF have received funding from the Ministry of Education and Culture (through the Academy of Finland), while FMI has received funding from the Ministry of Transport and Communication. The share of funding obtained from the two ministries has been 50%-50%. In 2020 UHEL and UEF did not receive funding from the Academy of Finland, but is trying to run and maintain the stations with the funding from the founder organisations, while the funding for FMI has remained unchanged. The next possibility to apply funding will be in 2021.



ICOS FINLAND PARTNERS AND FUNDERS

Academy of Finland
www.aka.fi/en

Finnish Meteorological Institute (FMI)
en.ilmatieteenlaitos.fi

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

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

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

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

Figure 16: The ICOS Finland station network. The numbers in the map correspond to the numbers in Table 16.

Table 16. ICOS Stations in Finland

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

ICOS France

ICOS FRANCE FOCAL POINT

Denis Loustau

French National Research Institute for Agriculture, Food, and Environment, INRAE

France

contact-france@lists.icos-ri.eu

+33 678 197 399

www.icos-france.fr

Saclay: an Atmosphere station of ICOS France.

The role of ICOS France

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

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

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

ICOS France infrastructure

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

The ICOS France network encompasses three ICOS observation domains: Atmosphere, Ecosystem and Ocean. The French network consists of 24 stations (Figures 17 a, b, c, d.) of which five are Atmosphere stations, eighteen are Ecosystem stations and one is an Ocean station (SOOP). Each station performs a set of measurements according to common specifications and under the control of the corresponding Thematic Centre. Class 1 and 2 stations form the main framework of the infrastructure and are committed for a period of 20 years.

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

The ICOS France funding structure

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

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

Figure 17a

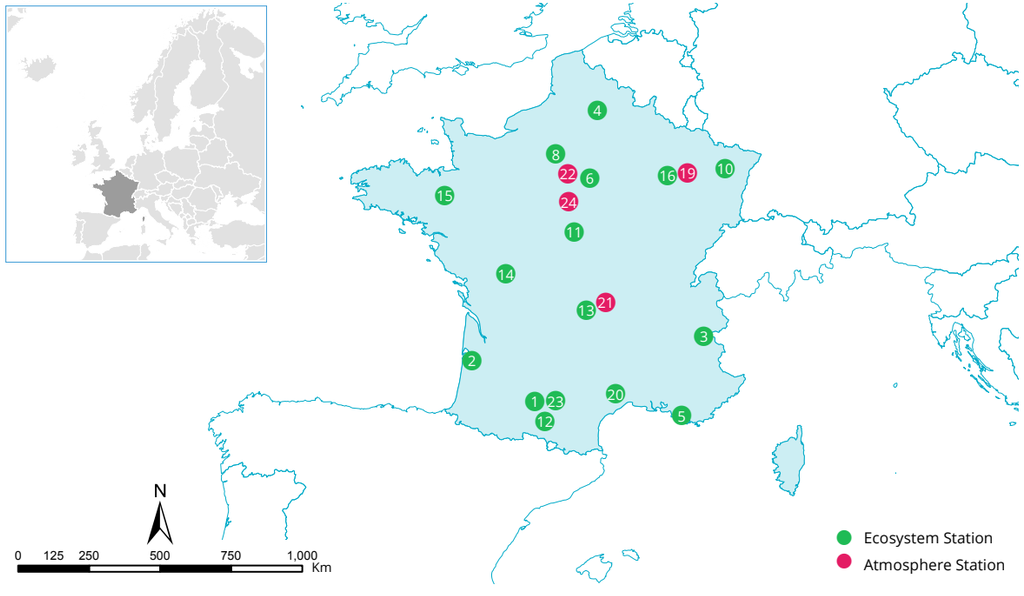


Figure 17b

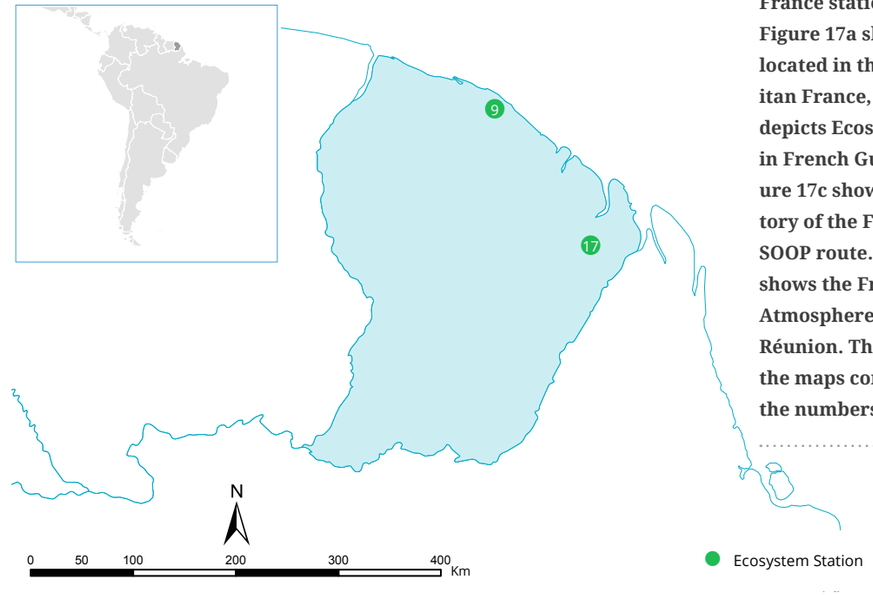


Figure 17: The ICOS France station network. Figure 17a shows stations located in the metropolitan France, Figure 17b depicts Ecosystem stations in French Guiana, and Figure 17c shows the trajectory of the France-Brazil SOOP route. Figure 17d shows the Franco-Belgian Atmosphere station in La Réunion. The numbers in the maps correspond to the numbers in Table 17.

Figure 17c

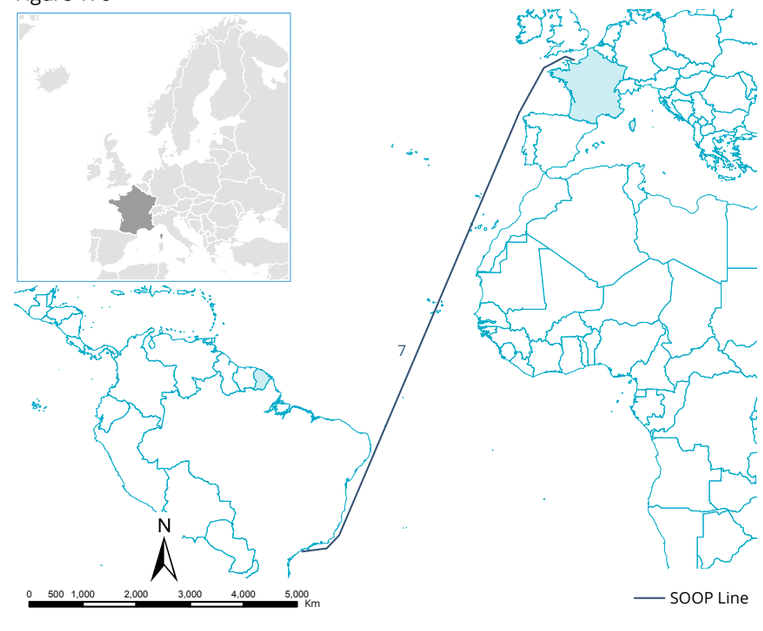
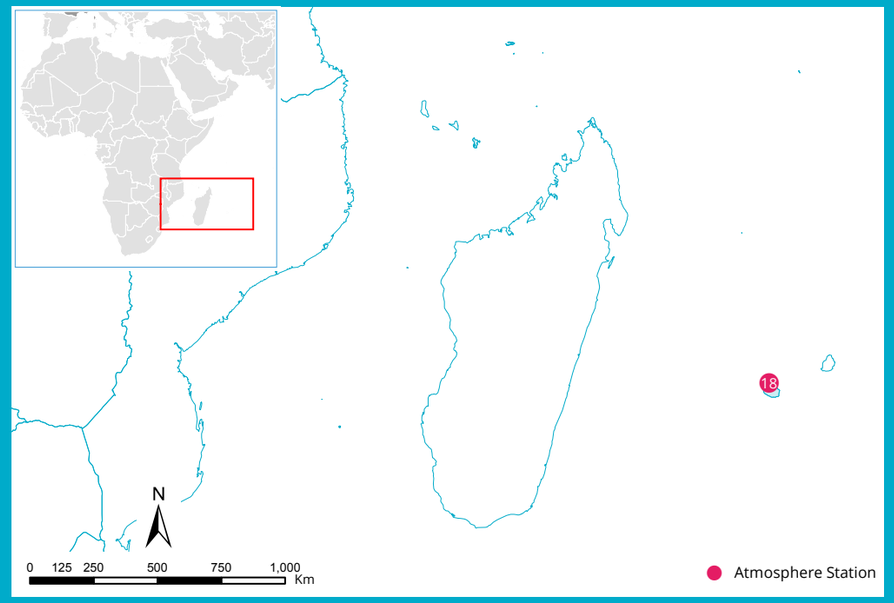


Figure 17d



ICOS FRANCE PARTNERS AND FUNDERS

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

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

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

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

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

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

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

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

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

French Geological Survey (BRGM)
www.brgm.eu

French Meteorological Institute
www.meteofrance.com

French National Museum of Natural History
www.mnhn.fr

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

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

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

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

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

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

University of Avignon
www.univ-avignon.fr

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

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

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

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

University of La Paz, Bolivia

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

University of Lorraine
welcome.univ-lorraine.fr

University of Montpellier
www.umontpellier.fr

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

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

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

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

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

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

Table 17. ICOS stations in France

MAP NUMBER	STATION NAME	STATION ABBREVIATION	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
1	Auradé	FR-Aur	Ecosystem	Cropland	Associated	The National Centre for Scientific Research
2	Bilos - Salles	FR-Bil	Ecosystem	Forest	Class 2	French National Research Institute for Agriculture, Food, and Environment
3	Col-du-Lautaret	FR-Clt	Ecosystem	Grassland	Associated	The National Centre for Scientific Research
4	Estrées-Mons	FR-EM2	Ecosystem	Cropland	Associated	French National Research Institute for Agriculture, Food, and Environment
5	Font-Blanche	FR-FBn	Ecosystem	Forest	Class 2	French National Research Institute for Agriculture, Food, and Environment
6	Fontaine-bleau-Barbeau	FR-Fon	Ecosystem	Forest	Class 1	The National Centre for Scientific Research
7	France-Brazil	FR-SOOP-France-Brazil	Ocean	SOOP	Class 1	CNRS-IRD-U. Paris-Sorbonne
8	Grignon	FR-Gri	Ecosystem	Cropland	Class 2	French National Research Institute for Agriculture, Food, and Environment
9	Guyaflux	GF-Guy	Ecosystem	Forest	Associated	French National Research Institute for Agriculture, Food, and Environment
10	Hesse	FR-Hes	Ecosystem	Forest	Class 1	French National Research Institute for Agriculture, Food, and Environment
11	La Guette	FR-LGt	Ecosystem	Peatland	Associated	The National Centre for Scientific Research

Table 17. ICOS stations in France

MAP NUMBER	STATION NAME	STATION ABBREVIATION	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
12	Lamasquère	FR-Lam	Ecosystem	Cropland	Class 1	The National Centre for Scientific Research
13	Laqueuille	FR-Lqu	Ecosystem	Grassland	Class 2	French National Research Institute for Agriculture, Food, and Environment
14	Lusignan	FR-Lus	Ecosystem	Grassland	Class 2	French National Research Institute for Agriculture, Food, and Environment
15	Méjusseaume	FR-Mej	Ecosystem	Grassland	Associated	French National Research Institute for Agriculture, Food, and Environment
16	Montiers-sur-Saulx	FR-MsS	Ecosystem	Forest	Associated	French National Radioactive Waste Management Agency
17	Nouragues	GF-Nrg	Ecosystem	Forest	Associated	The National Centre for Scientific Research
18	Observatoire de l'Atmosphère du Maïdo	RUN	Atmosphere	Tall tower	Class 2	University of La Réunion
19	Observatoire Pérenne de l'Environnement	OPE	Atmosphere	Tall tower	Class 1	French National Radioactive Waste Management Agency
20	Puechabon	FR-Pue	Ecosystem	Forest	Class 2	The National Centre for Scientific Research
21	Puy de Dôme	PUY	Atmosphere	Mountain	Class 2	CEA-CNRS
22	Saclay	SAC	Atmosphere	Tall tower	Class 1	CEA-CNRS-UVSQ
23	Toulouse	FR-Tou	Ecosystem	Grassland	Associated	CNRM, University of Toulouse, Météo-France, CNRS
24	Trainou	TRN	Atmosphere	Tall tower	Class 2	CEA-CNRS

ICOS Germany

ICOS GERMANY FOCAL POINT

Christian Brümmer

Senior Researcher

Thünen Institute of Climate-Smart Agriculture

Braunschweig, Germany

contact-germany@lists.icos-ri.eu

+49 531 596 2614

www.icos-infrastruktur.de

Fendt: an Ecosystem station of ICOS Germany.

The role of ICOS Germany

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

Germany's featured station within the ICOScapes photo campaign was the Ecosystem site Fendt. Its location and site management 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 Laboratories. It is an ideal location due to its specific expertise in the high-precision analysis of trace gases, the provision of calibration standards for the observation networks, and in the analysis of the radioactive carbon isotope ^{14}C in air samples.

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

The ICOS Germany infrastructure

ICOS Germany comprises 35 stations (Figures 18a, b; Table 18), and they are categorised into three station/observation networks: Atmosphere, Ecosystem and Ocean. The network is operated by 16 national research centres, universities and federal research institutions.

The Atmosphere station network covers the continuous monitoring of atmospheric greenhouse gas concentrations (CO_2, CH_4 and N_2O) combined with flask samples for their isotopic composition, radiocarbon sampling and tracer measurements (CO and ^{222}Rn) from a network of 12 observation stations at tall towers 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 18 stations with the use of the eddy covariance technique. The flux stations are mainly arranged in clusters, with different ecosystems being exposed to similar climatic conditions.

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

The ICOS Germany funding structure

ICOS Germany is funded by the German Federal Ministries 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

Technische Universität Dresden
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.uni-heidelberg.de

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

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

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

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

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

Thünen Institute
www.thuenen.de/en

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

University of Freiburg
www.uni-freiburg.de

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

Umweltbundesamt (UBA)
www.umweltbundesamt.de/en

Figure 18a

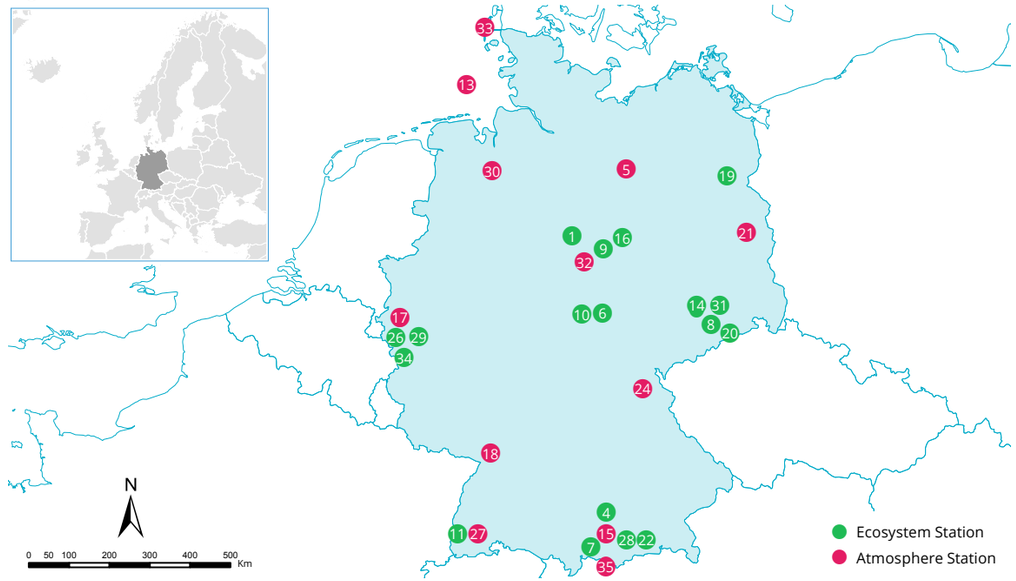


Figure 18b

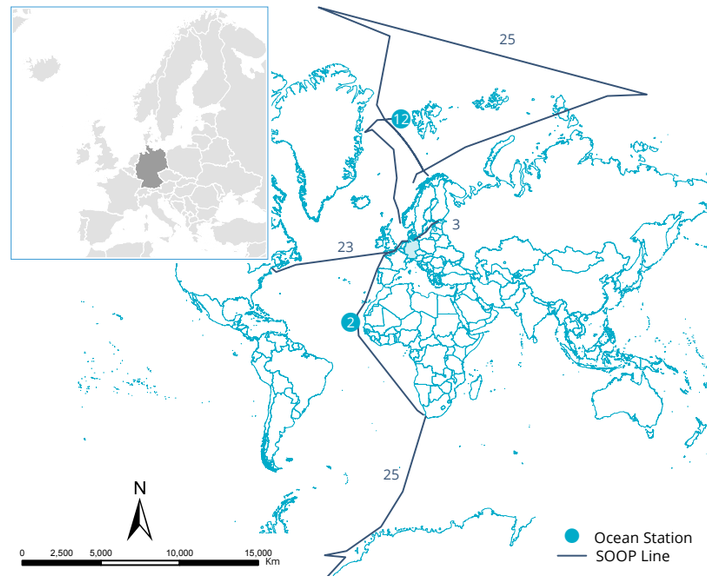


Figure 18: The ICOS Germany station network. Figure 18a shows the stations in mainland Germany, while Figure 18b depicts remote Ocean stations and SOOP lines. The numbers in the maps correspond to the numbers in Table 18.

Table 18. ICOS Stations in Germany

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

Table 18. ICOS Stations in Germany

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

* To be declared later

ICOS Italy

ICOS ITALY FOCAL POINT
Carlo Calfapietra
National Research Council (CNR)
Director
Institute of Research on Terrestrial Ecosystems Italy

contact-italy@lists.icos-ri.eu
+39 0763 3749 17
www.icos-italy.it

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 17 stations (Figure 19; Table 19a), of which three are Atmosphere stations, five are Ecosystem stations, five 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 (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 characterised by personnel and owned instrumentation.

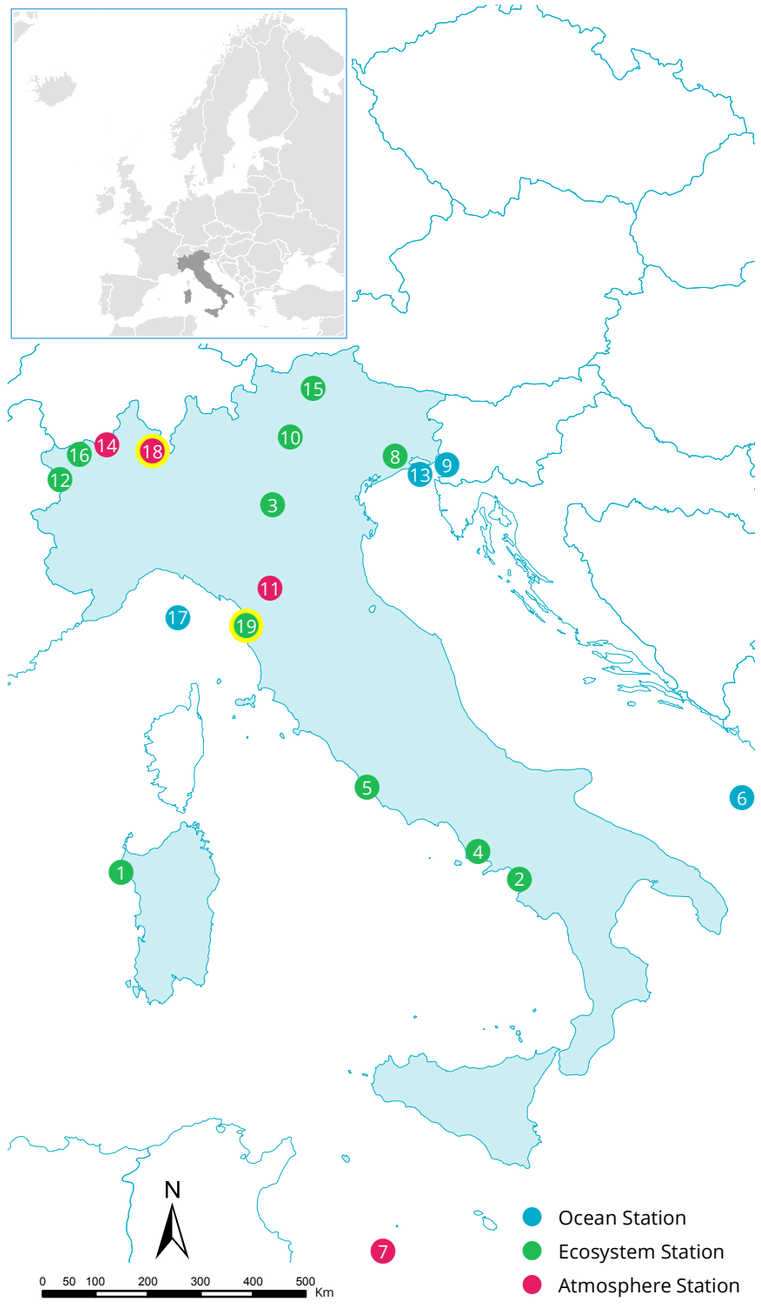


Figure 19: The ICOS Italy station network. Atmosphere station Ispra (IPR) and Ecosystem station San Rossore 2 (IT-SR2) are run by the EU Joint Research Centre and they are highlighted on the map. The numbers in the map correspond to the numbers in Tables 19a and 19b.

KUVA

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

National 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 19a. ICOS Stations in Italy

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

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

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

ICOS Netherlands

ICOS NETHERLANDS FOCAL POINT
Bart Kruijt
Wageningen University
The Netherlands

contact-netherlands@lists.icos-ri.eu
+31 317 486 440
www.icos-infrastructure.nl

Loobos: an Ecosystem station of ICOS Netherlands.

The role of ICOS Netherlands

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

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

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

The ICOS Netherlands infrastructure

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

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

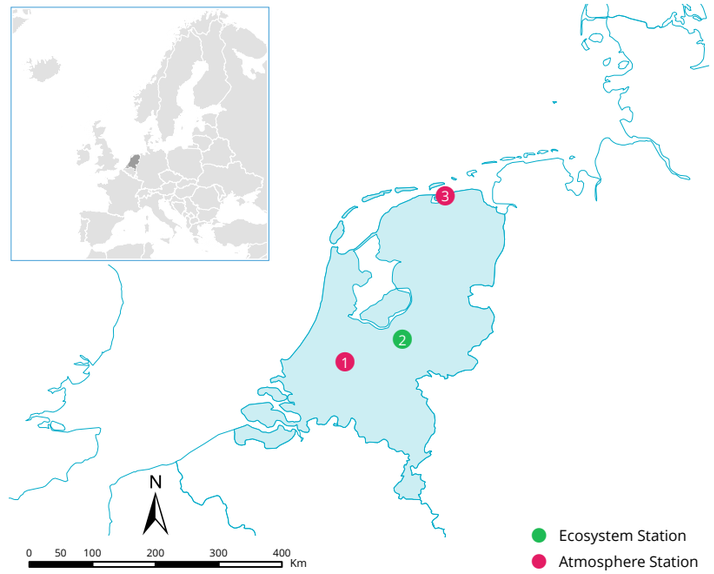


Figure 20: The ICOS Netherlands station network. The numbers in the map correspond to the numbers in Table 20.

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

The Ecosystem station Loobos will enter the Class 2 labelling programme during 2020. 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

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

ICOS Norway

ICOS NORWAY FOCAL POINT

Stephen Matthew Platt

Senior Scientist

Norwegian Institute for Air Research, NILU

Norway

contact-norway@lists.icos-ri.eu

+47 63 89 81 33

no.icos-cp.eu

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-

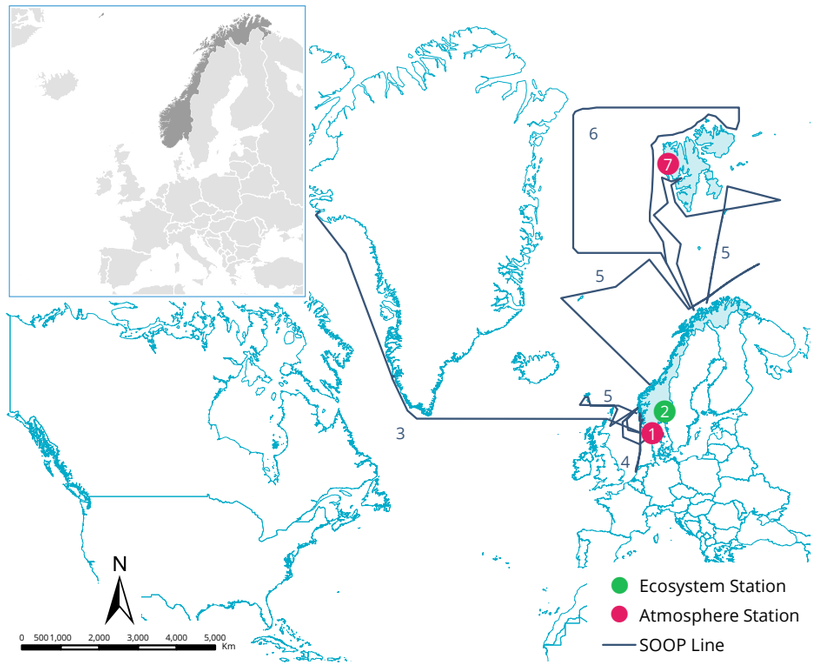


Figure 21: The ICOS Norway station network showing the stations located in mainland Norway, remote Atmosphere stations and SOOP lines. The numbers in the map correspond to the numbers in Table 21.

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

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

ICOS NORWAY PARTNERS AND FUNDERS

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

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

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

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

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

Norwegian Polar Institute
www.npolar.no/en/

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

The Research Council of Norway
www.forskningsradet.no/

University of Bergen
www.uib.no/en

Table 21. ICOS Stations in Norway

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

ICOS Sweden

ICOS SWEDEN FOCAL POINT
Maj-Lena Linderson
Senior Lecturer
Lund University
Sweden

contact-sweden@lists.icos-ri.eu
+46 46 222 00 00
www.icos-sweden.se

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 destabilise 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

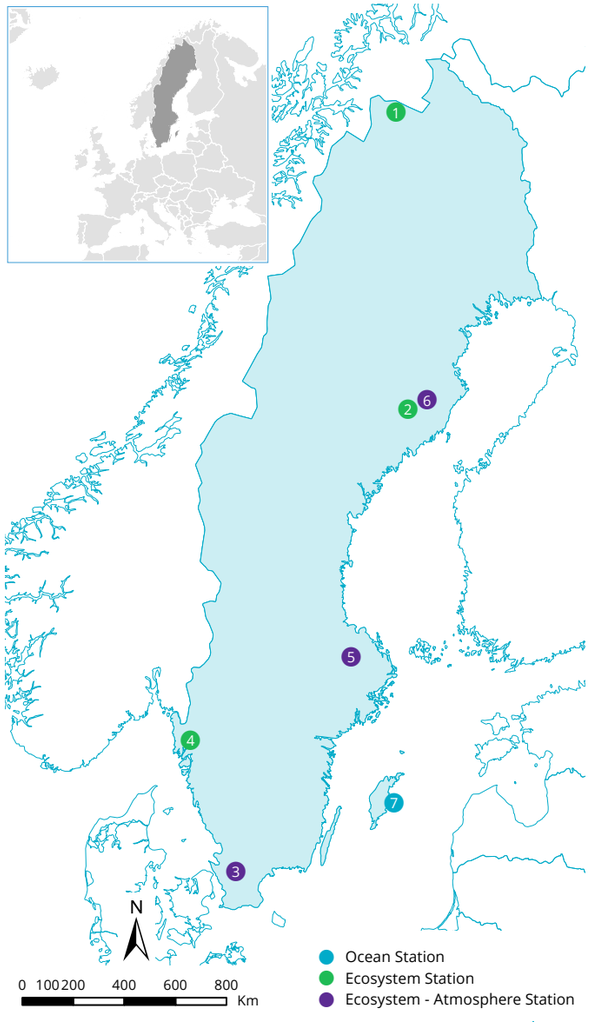
ICOS Sweden is a national research infrastructure presently consisting of a consortium of five partners: Lund University, Gothenburg University, the Swedish University of Agricultural Sciences, Uppsala University, and the Swedish Polar Research Secretariat. In 2021, the Swedish Meteorological and Hydrological Institute (SMHI) will enter the consortium as host of the Tavastland Ocean station. Lund University hosts the consortium and the coordination office, with the director of ICOS Sweden also acting as the national Focal Point. All the partners of ICOS Sweden have active roles in many subfields within atmospheric, marine, and earth systems science.

ICOS Sweden contributes to observations in all three ICOS observation networks: Atmosphere, Ecosystem, and Ocean. The ICOS Sweden network consists of ten 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, representing a north-south gradient in the country.

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

All three Atmosphere stations received the ICOS label in 2018. Hyltemossa, Norunda and Degerö Ecosystem stations received the ICOS label in 2018–2019. The remaining stations are expected to be labelled in 2021. Several stations are co-located with other RIs such as ACTRIS, SITES (a national RI for terrestrial and limnologic field research) and NordSpec (a research network for spectral data collection).

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



ICOS SWEDEN PARTNERS AND FUNDERS

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

Lund University
www.lunduniversity.lu.se

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

Uppsala University
www.uu.se/en

University of Gothenburg
www.gu.se/english

Swedish Polar Research Secretariat
polar.se/en

The ICOS Sweden funding structure

Funding for the construction and operations of ICOS Sweden is provided by the Swedish Research Council (SRC) and the consortium partners. The Swedish Research Council covers around 40–45 percent of the costs for the present (2016–2020) and coming (2021–2024) funding periods, while the consortium partners together cover 55–60 percent of the costs.

Table 22. ICOS Stations in Sweden

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

ICOS Switzerland

ICOS SWITZERLAND FOCAL POINT
Nina Buchmann
Professor
ETH Zurich
Switzerland

contact-switzerland@lists.icos-ri.eu
+41 44 632 39 59
www.icos-switzerland.ch

Davos: the Ecosystem station of ICOS Switzerland.

The role of ICOS Switzerland

The ICOS Switzerland 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.

Since the Alpine region will be strongly affected by climate change, information about it is absolutely crucial. The impacts not only include glacier retreat, thawing of permafrost, and natural hazards like rock falls and landslides, but also consequences for the regional water cycle and long-term storage of carbon. Ecosystems adapted to low temperatures will be particularly sensitive to climate warming.

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

The ICOS Switzerland infrastructure

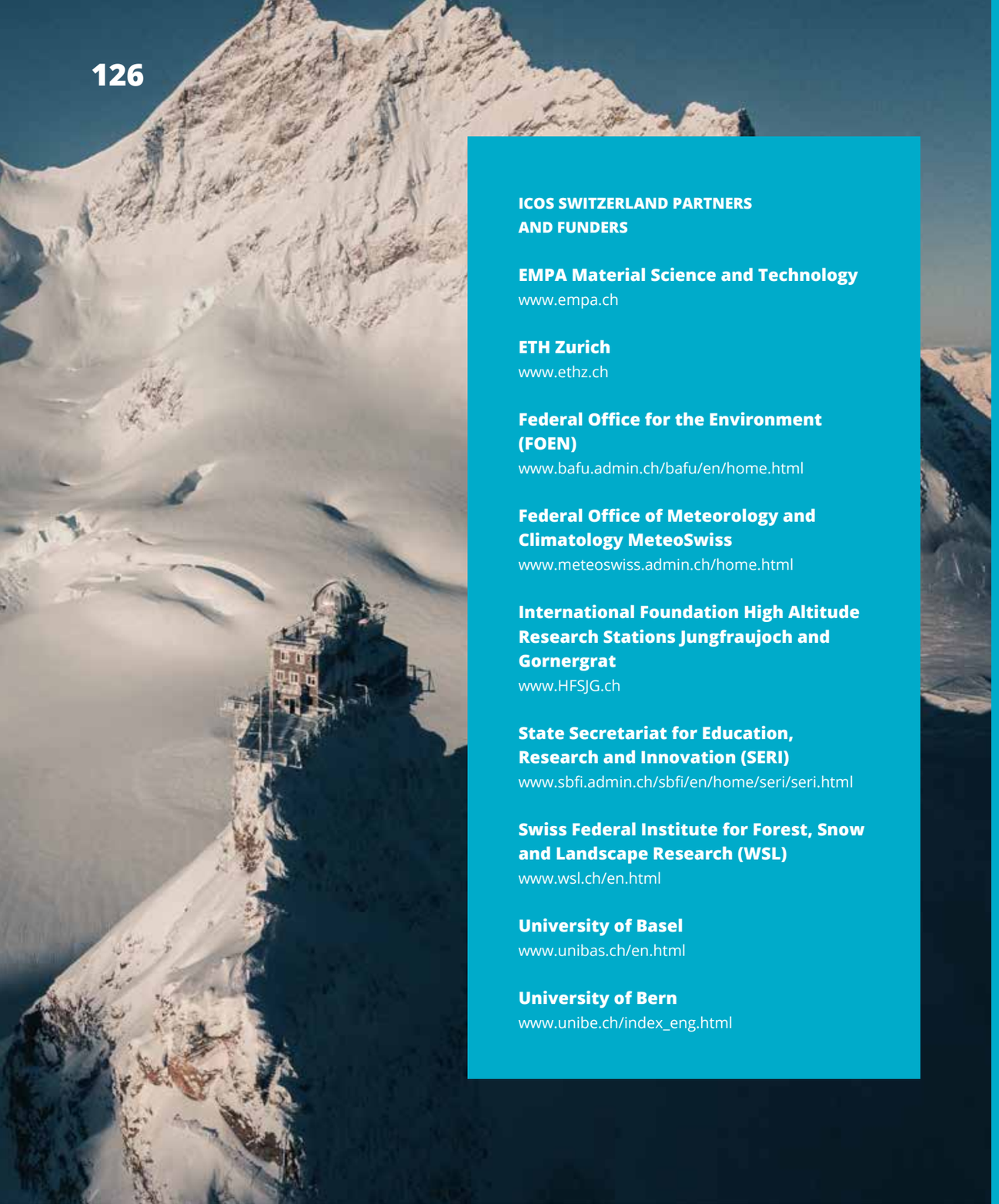
The ICOS Switzerland consortium consists of ETH Zurich (National Focal Point), Empa, WSL, the University of Bern, the University of Basel, and Meteo Swiss.

ICOS Switzerland contributes to two ICOS RI observation networks and consists of one Atmosphere station (Jungfraujoch) and one Ecosystem station (Davos) (Figure 23; Table 23). Jungfraujoch, located at 3,580 metres above sea level, is the highest, permanently manned research station in Europe and the highest measurement station in the ICOS network. Continuous in-situ measurements of reactive gases started in Jungfraujoch in 1973, and measurements of greenhouse gases were initiated in 2000. Due to its elevation and distance from major greenhouse gas sources and sinks, Jungfraujoch station is mainly exposed to air masses representing pristine conditions. This information on the background conditions over Central Europe is of key importance in quantifying emission strengths in more polluted environments. 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 Jungfraujoch allows the unravelling of different greenhouse gas sources and sink areas over a large part of Central Europe.

Davos is the only subalpine Norway 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 of CO_2 and H_2O vapour since 1997. This allows detecting impacts of slow climate change on the carbon sink capacity of the high elevation forest over time. Moreover, detailed functional, e.g. ecophysiological, assessments allow to study how the forest responds to extreme weather events predicted to increase in frequency due to climate change. The long-term data of the two stations are openly available, not only to scientists but also to other user communities and stakeholders.

The ICOS Switzerland funding structure

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



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

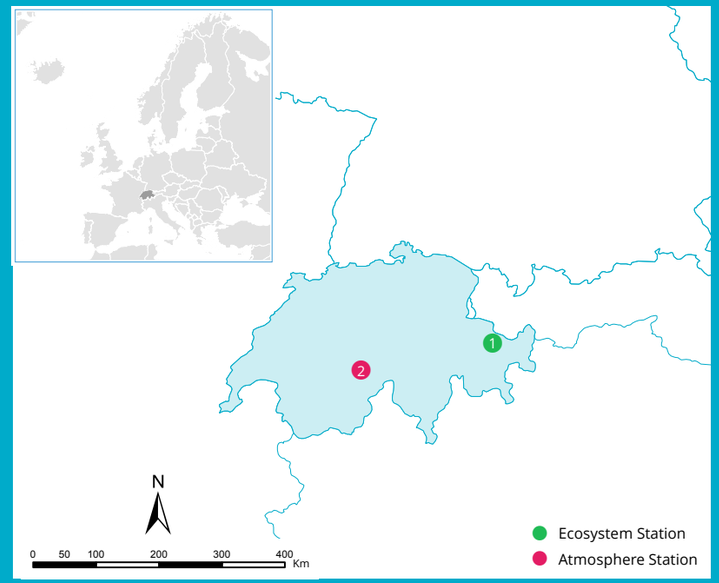
University of Basel
www.unibas.ch/en.html

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

Table 23. ICOS Stations in Switzerland

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

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



ICOS United Kingdom

ICOS UK FOCAL POINT
Andrew Watson
Professor
University of Exeter
UK

contact-uk@lists.icos-ri.eu
+44 1392 7237 92
www.icos-uk.org

Auchencorth Moss: an Ecosystem station of ICOS UK.

The role of ICOS UK

The Atmosphere Observation network of the ICOS United Kingdom (UK) is designed to allow the entire greenhouse gas budget of the UK to be determined and to quantify the impact of urban landscapes on this budget. The Ecosystem Observation network of ICOS UK is designed to account for the heterogeneity present in UK landscape types and climate, and 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 six stations (Table 24; Figure 24). At present, ICOS UK has one Ecosystem station (Auchencorth Moss, led by the

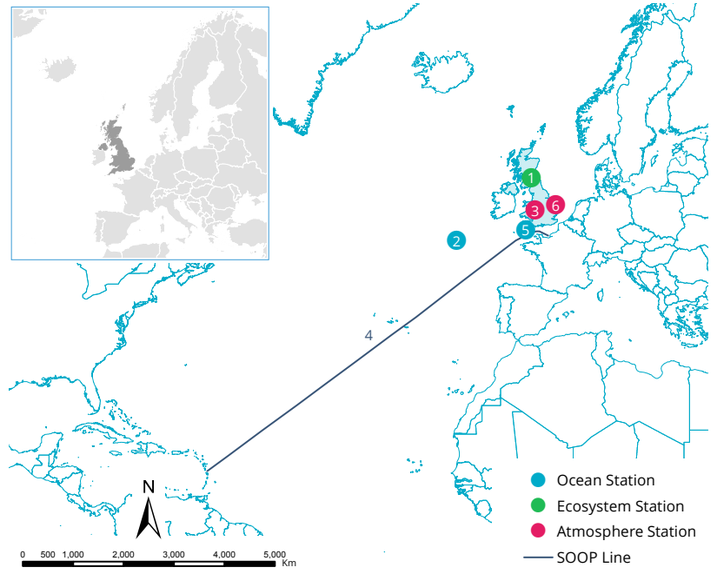


Figure 24: The ICOS UK station network showing stations located around mainland UK and the route across the North Atlantic Ocean for the UK-Caribbean SOOP line. The numbers in the map correspond to the numbers in Table 24.

Centre of Ecology & Hydrology); two Atmosphere stations (Ridge Hill, led by the University of Bristol, and Weybourne, led by the University of East Anglia) and three Ocean stations: the UK-Caribbean SOOP 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 SOOP 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 Ridge Hill Atmosphere station (University of Bristol) measures greenhouse and ozone-depleting gases from tall telecommunication towers. High-frequency measurements of all major greenhouse gases are made at Ridge Hill, including CO_2, CH_4, NO, SF_6 and a suite of halocarbons. Data from the UK network are used to assess atmospheric trends and UK emissions of these gases.

The Western Channel Observatory is an oceanographic time-series and marine biodiversity reference site in the Western English Channel. Auchencorth Moss is part of a sensitive peatland ecosystem in central southern Scotland. The latter is a valuable location for long-term monitoring of surface/atmospheric exchange fluctuations and measurements indicating environmental change.

The ICOS UK funding structure

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

ICOS UK PARTNERS AND FUNDERS

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

MET Office
www.metoffice.gov.uk

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

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

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

University of Bristol
www.bristol.ac.uk

University of East Anglia
www.uea.ac.uk

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

Table 24. ICOS Stations in the United Kingdom

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

8 PROSPECTIVE COUNTRIES: Future members of ICOS ERIC

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

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

In the framework of the European Horizon 2020 project RINGO, nine countries are cooperating with ICOS in order to increase their readiness to become members of ICOS ERIC: Estonia, Greece, Hungary, Ireland, Poland, Portugal, Romania, South Africa and Spain. Of these, Poland and Spain have announced their plan to join in 2020: they are presented in the following pages.

ICOS Poland

ICOS POLAND FOCAL POINT
Janusz Olejnik
Professor
Poznan University of Life Sciences
Poland

janusz.olejnik@up.poznan.pl
+48 512 453 888

Mezyk: an Ecosystem station of ICOS Poland.

The role of ICOS Poland

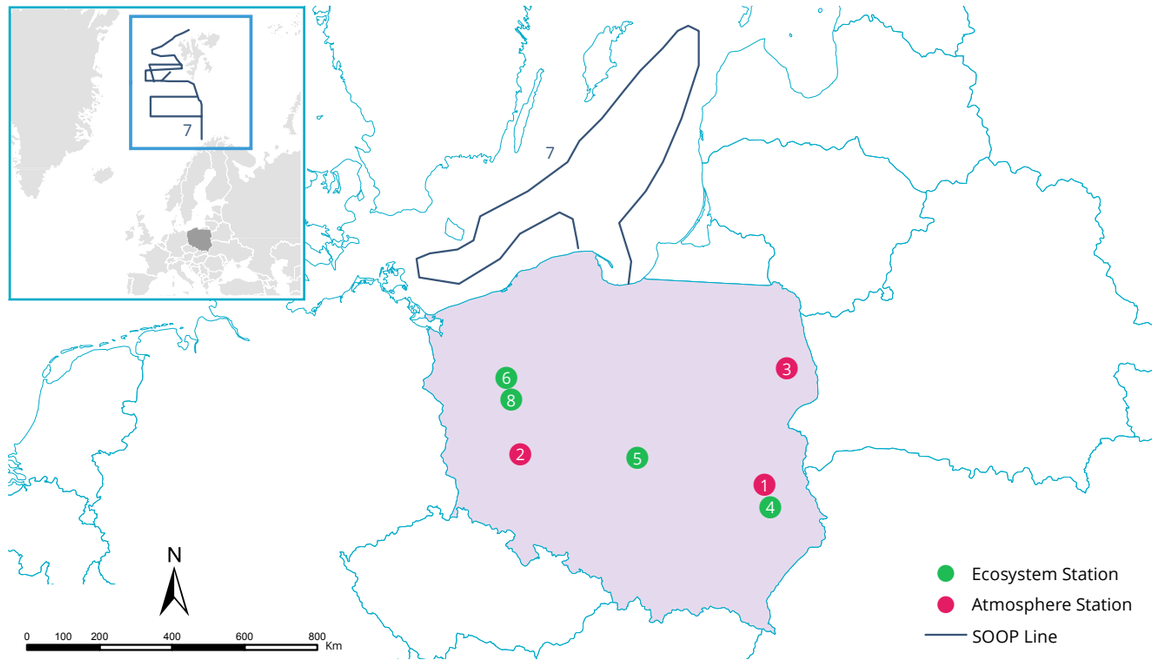
The main goal of ICOS Poland is the long-term research of the carbon cycle with the focus on the greenhouse gas exchanges between the most representative terrestrial ecosystem types, the Baltic Sea and the atmosphere. Combining measurements of the atmosphere, ecosystems and the ocean, the ICOS Poland infrastructure enables to determine the effects of land use changes and climate variability on the territory of Poland. ICOS Poland covers the eastern part of Central Europe and will be the easternmost country within the ICOS RI.

The ICOS Poland infrastructure

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

ICOS Poland will consist of eight stations, of which five are already operating (built during the CarboEurope/NitroEurope projects) and three stations will be built in the near future. These comprise four ecosystem, three atmosphere and one ocean station (the Pomerania ship at the Baltic Sea). The

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



ecosystem stations are located in different ecosystems which partly represent the mosaic land-use structure in Poland: forest, agriculture and wetland. The urban station is situated in Lodz, the third largest city of Poland. The triangular placement of the atmosphere stations covers a significant part of the Polish territory: two of the atmosphere stations are located on the east side of Poland along the borders with Belarus and Ukraine, and the third atmosphere station is in the middle west of Poland.

The ICOS Poland funding structure

ICOS Poland will be funded by two ministries: the Ministry of Science and Higher Education (40% of total budget for the first 3 years) and the Ministry of Climate (60% for the next 12 years).

A LIST OF ICOS POLAND PARTNERS AND FUNDERS

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

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

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

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

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

Poznan University of Life Sciences (PULS)
msc-bsc.puls.edu.pl

University of Lodz (UOL)
iso.uni.lodz.pl/

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

Table 25. The future ICOS Poland stations network

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

* To be declared later

ICOS Spain

ICOS SPAIN FOCAL POINT

Melchor González-Dávila

Professor

Institute for Oceanography and Global Change (IOCAG), University of Las Palmas de Gran Canaria (ULPGC)

melchor.gonzalez@ulpgc.es

+34 928 452 914

Emilio Cuevas

Head of the Izaña Atmospheric Research Centre, State Meteorological Agency of Spain (AEMET)

ecuevasa@aemet.es

+34 922 151 718

Izaña: an Atmosphere station of ICOS Spain.

The role of ICOS Spain

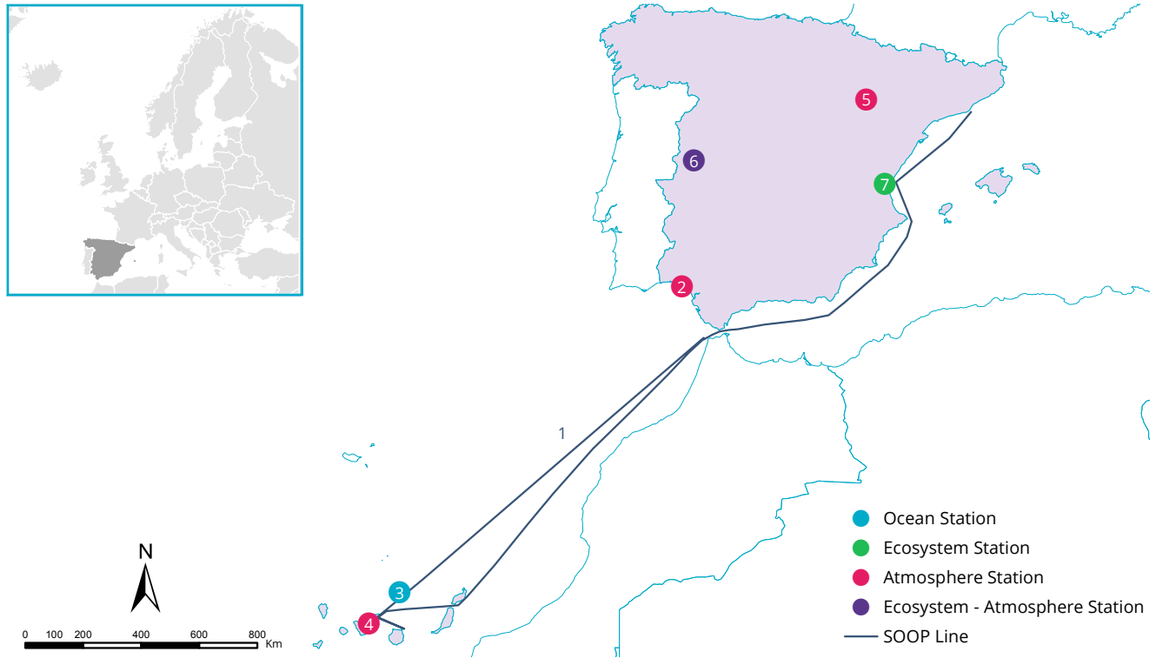
The main goal of ICOS Spain is to considerably expand the geographical coverage of the ICOS RI observations in all three observation domains. The ICOS Spain station network covers south-western Europe, extending the ICOS observations to the subtropical North Atlantic on the Canary Islands. The Spanish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

The Spanish Atmosphere stations contribute to unique background measurements of GHGs. These stations include, for instance, the historical Izaña Atmosphere station, located in Tenerife, the Canary Islands, and the combined Atmosphere-Ecosystem station of Majadas de Tiéta located on the Iberian Peninsula. The Ecosystem stations provide otherwise scarce data on extremely dry natural and agricultural ecosystems in Europe, where productivity and sustainability are challenged by climate change.

The ICOS Spain infrastructure

The ICOS Spain infrastructure is coordinated by the State Meteorological Agency of Spain (AEMET), participating the QUIMA group of the Instituto de Oceanografía y Cambio Global – University of Las Palmas de Gran Canaria (ULPGC), the Mediterranean Center for Environmental Studies (CEAM), the Institute of Environmental Science and Technology (ICTA) of the Autonomous University of Barcelona (UAB), the Oceanic Platform of the Canary Islands (PLOCAN) and the National Institute of Aerospace

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



Technology (INTA). These partners have a leading role in climate modelling and research, and regional greenhouse gas measurements in Spain.

ICOS Spain comprises eight stations, of which four are Atmosphere stations, two are Ecosystem stations and two are Ocean stations. Most of the stations are integrated to several existing international observation networks. For example, the Izaña atmosphere station belongs to the Total Carbon Column Observing Network (TCCON), the ecosystem station of Majadas de Tiétar is part of FLUXNET, and the ESTOC ocean station contributes to the Surface Ocean CO_2 Atlas (SOCAT). Several of the stations are co-located with other research infrastructures such as the European Research Infrastructure for the observation of Aerosol, Clouds and Trace Gases (ACTRIS).

The Izaña Atmosphere station has a long and globally important history of background reference CO_2 and CH_4 measurements. The station belongs to the WMO GAW program and runs quality control/assurance audits conducted by the Swiss Federal Laboratories for Materials Science and Technology (Empa). The three mainland Atmosphere stations located in the Iberian Peninsula provide important information on the air mass transport from the Atlantic Ocean, the Western Mediterranean and Central Europe. The Atmosphere stations of La Muela and El Arenosillo have synergies between regional and international levels with established atmospheric observational programs.

The combined Atmosphere and Ecosystem station of Majadas de Tiétar is located in a holm oak tree and grass landscape, the type of agroforestry system. This unique Mediterranean area has a high ecological and cultural value and it covers large parts of the south-western Iberian Peninsula that is particularly vulnerable to climate change. The station takes actively part in European remote sensing activities.

A LIST OF ICOS SPAIN PARTNERS AND FUNDERS

Institute of Environmental Science and Technology (ICTA), Autonomous University of Barcelona (UAB)
www.uab.cat

Mediterranean Center for Environmental Studies (CEAM)
www.ceam.es/GVAceam/ceam_en

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

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

Oceanic Platform of the Canary Islands (PLOCAN)
www.plocan.eu/en/home

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

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

Table 26. ICOS Spain stations network

MAP NUMBER	STATION NAME	STATION ABBREVIATION	STATION TYPE	SITE TYPE	STATION CLASS	HOST INSTITUTE
1	CanOA	*	Ocean	SOOP line	Class 1	University of Las Palmas de Gran Canaria
2	El Arenosillo	*	Atmosphere	Tall Tower	Class 2	National Institute of Aerospace Technology
3	ESTOC	*	Ocean	Fixed time series	Class 1	University of Las Palmas de Gran Canaria
4	Izaña	IZO	Atmosphere	Mountain	Class 2	State Meteorological Agency of Spain
5	La Muela	LMU	Atmosphere	Tall tower	Class 2	Institute of Environmental Science and Technology, Autonomous University of Barcelona
6	Majadas de Tiétar	*	Atmosphere	Tall tower	Class 2	State Meteorological Agency of Spain
6	Majadas de Tiétar	*	Ecosystem	Holm oak forest	Class 2	Mediterranean Center for Environmental Studies
7	Valencia	*	Ecosystem	Cropland	Associated	Mediterranean Center for Environmental Studies

* To be declared later

The ESTOC Ocean station in the north of the Canary Islands monitors the air–sea CO_2 fluxes and ocean acidification. It has the longest history of ocean carbon dioxide and pH time series observations in Europe. The station is complemented with the CanOA SOOP line that operates between the Canary Islands and Barcelona through the Strait of Gibraltar and the West Mediterranean Sea.

The ICOS Spain funding structure

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

9 APPENDICES

Terms and definitions

TERMS	DEFINITIONS
Carbon Portal	The combined real and virtual data centre in which ICOS observational and elaborated data products and associated metadata are stored, archived, accessed and curated.
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.
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	(REWRITE)The Operational Unit in which work the administrative staff in charge of supporting the Director General in ICOS ERIC's day-to-day management and that is mainly located on the premises of the statutory seat but may also have components in other countries.
Host Contribution	The financial support of Members or Observers hosting an ICOS Central Facility.
Host Premium Contribution	The financial support of Members or Observers hosting an ICOS Head Office and Carbon Portal.
ICOS Research Infrastructure (ICOS RI)	The distributed research infrastructure that is coordinated by ICOS ERIC and involves Central Facilities and ICOS NNs.

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

ABBREVIATION	FULL NAME
^{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 Laboratories
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
COP	The informal name for the Conference of the Parties to the United Nations' Framework Convention on Climate Change (UNFCCC)
CO_2	Carbon dioxide
CRL	Central Radiocarbon Laboratory of CAL
DG	Director General of the ICOS RI
DOI	Digital Object Identifier
EAB	ICOS Ethical Advisory Board
EGU	The European Geosciences Union
ENVRI	European Environmental Research Infrastructures
ERIC	European Research Infrastructure Consortium
ESFRI	European Strategy Forum on Research Infrastructures

ABBREVIATION	FULL NAME
ETC	ICOS Ecosystem Thematic Centre
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
GEOSS	Global Earth Observation System of Systems
GHGs	Greenhouse gases
GLODAP	The Global Ocean Data Analysis Project
GTOS	Global Terrestrial Observing System
GNI	Gross National Income
ICOS	Integrated Carbon Observation System
ICOS RI	ICOS Research Infrastructure
ICOS RICOM	ICOS Research Infrastructure Committee
IG3IS	Integrated Global Greenhouse Gas Information System
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

Members of the ICOS General Assembly

COUNTRY	NAME	AFFILIATION
Belgium	Michele Oleo	Department of Economy, Science and Innovation (EWI), Flemish Government
Belgium	Aline van der Werf	Belgian Science Policy Office (BELSPO)
Czech Republic	Jiří Kolman	Global Change Research Institute of the Czech Academy of Sciences (CzechGlobe)
Czech Republic	Michal Marek	Global Change Research Institute of the Czech Academy of Sciences (CzechGlobe)
Czech Republic	Petr Ventluka	Ministry of Education, Youth and Sports of Czech Republic
Denmark	Christine Hagberg	Danish Agency for Science and Higher Education
Denmark	Kim Pilegaard	Technical University of Denmark
Denmark	Troels Rasmussen	Danish Agency for Science and Higher Education
Denmark	Stine Vad Bovtrup	Danish Agency for Science and Higher Education
Finland	Ritva Dammert	University of Helsinki
Finland	Petteri Kauppinen	Finnish Ministry of Education and Culture
Finland	Hannele Korhonen	Finnish Meteorological Institute
France	Bruno Blanke	National Centre for Scientific Research (CNRS)
France	Thierry Caquet	French National Research Institute for Agriculture, Food, and Environment (INRAE)
France	Jean-Marie Flaud (Chair)	French Ministry of Higher Education, Research and Innovation
France	Valerie Moulin	The French Alternative Energies and Atomic Energy Commission (CEA)
Germany	Christian Plass-Dülmer	German Weather Service Deutscher Wetterdienst (DWD)
Italy	Cecilia Di Carlo	Italian Ministry of Education, Universities and Research (MIUR)
Italy	Gelsomina Pappalardo	National Research Council (CNR)
Italy	Lucia Perugini	Euro-Mediterranean Center on Climate Change (CMCC)
The Netherlands	Bernard Westerop	Dutch Research Council (NWO)

(continues) Members of the ICOS General Assembly

COUNTRY	NAME	AFFILIATION
Norway	Jon Børre Ørbæk	Research Council of Norway
Sweden	Magnus Friberg	Swedish Research Council
Sweden	Sara Moa	Swedish Research Council
Switzerland	Regine Röthlisberger	Federal Department of the Environment, Transport, Energy and Communications (DETEC)
United Kingdom	Douglas Connelly	National Oceanography Centre
United Kingdom	Sophie Hodgson	UK Research and Innovation (UKRI)

Situation in 15.6.2020

Members of the ICOS Scientific Advisory Board

NAME	TITLE AND AFFILIATION
Anna Michalak (Chair)	Interim Director, Department of Global Ecology, Carnegie Institution for Science
Ankur Desai (Co-Chair)	Professor, Department of Atmospheric and Oceanic Sciences, University of Wisconsin–Madison
James Butler	Director, NOAA Global Monitoring Laboratory
Sonia Seneviratne	Professor, Department of Environmental Systems Science, ETH Zurich
Rik Wanninkhof	Senior Scientist, NOAA Atlantic Oceanographic and Meteorological Laboratory

Situation in 15.6.2020

Abbreviations

ABBREVIATION	FULL NAME
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
RI	Research Infrastructure
SAB	Scientific Advisory Board
SBSTA	Subsidiary Body for Scientific and Technical Advice
SF_6	Sulphur hexafluoride
SOCAT	Surface Ocean CO_2 Atlas
SOOP	Ship of Opportunity
TCs	Thematic Centres for Atmosphere, Ecosystem and Ocean observations (ATC, ETC and OTC)
UNFCCC	United Nations' Framework Convention on Climate Change
WMO	World Meteorological Organisation

The most significant EU projects of ICOS in 2020

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.
e-shape	E-shape is an initiative that brings together decades of public investment in Earth Observation and in cloud capabilities into services for the decision-makers, the citizens, the industry and the researchers.
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).

10 CONTACTS

ICOS ERIC Head Office
Erik Palménin aukio 1
FI-00560 Helsinki
Finland
info@icos-ri.eu

ICOS Carbon Portal
Lund University, Geocentrum II
Sölvegatan 12
22362 Lund
Sweden
info@icos-cp.eu

Atmosphere Thematic Centre (ATC)
Leonard Rivier
LSCE-Orme, point courrier 129, CEA-Orme des Merisiers
F-91191 Gif-sur-Yvette, CEDEX
France
contact-atc@lists.icos-ri.eu

Ecosystem Thematic Centre (ETC)
Dario Papale
DIBAF University of Tuscia, Largo dell'Università – Blocco D
01100 – Viterbo
Italy
contact-etc@lists.icos-ri.eu

Ocean Thematic Centre (OTC)
Richard Sanders
Nygårdsgaten 112
5008 Bergen
Norway
contact-otc@lists.icos-ri.eu

Central Analytical Laboratories (CAL)

ICOS - Flask and Calibration Laboratory (FCL)
Armin Jordan
Technologie Center am Felsenkeller (TCF) – Eingang C
Kahlaische Str. 4
07745 Jena
Germany
contact-fcl@lists.icos-ri.eu

ICOS – Central Radiocarbon Laboratory (CRL), Karl Otto Münnich ^{14}C Laboratory
Samuel Hammer
Heidelberg University
Institute of Environmental Physics
Berliner Straße 53
69120 Heidelberg
Germany
contact-crl@lists.icos-ri.eu

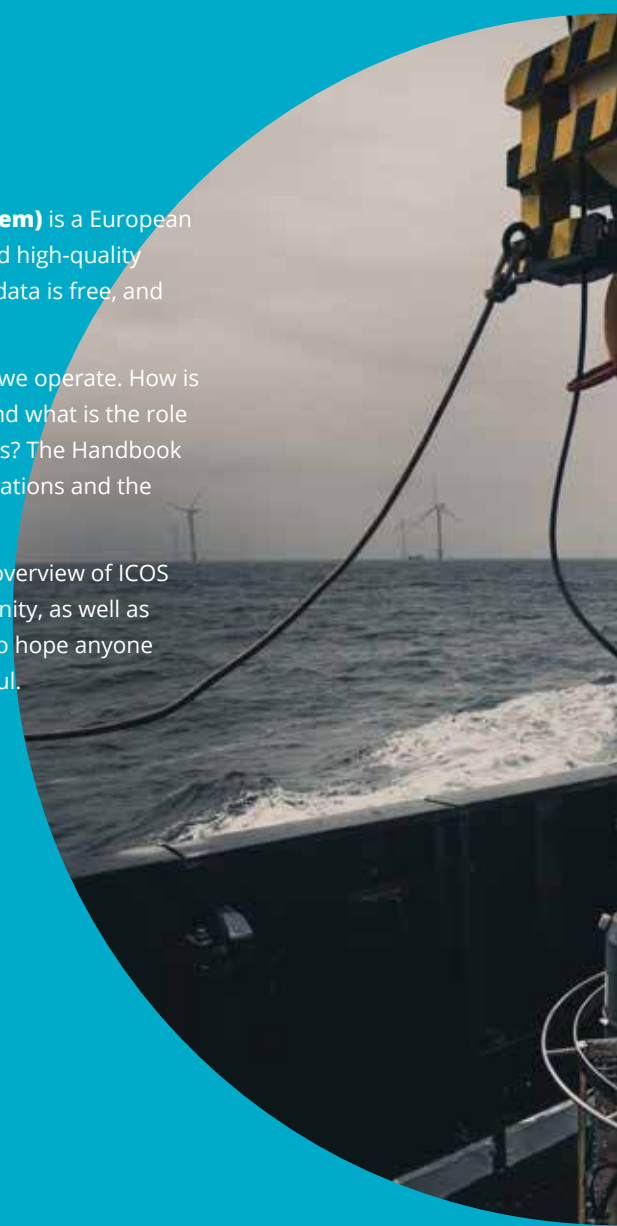
www.icos-ri.eu
instagram.com/icosri
twitter.com/icos_ri
linkedin.com/company/integrated-carbon-observation-system

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. Our data is free, and open for all users.

The ICOS Handbook helps to understand how we operate. How is ICOS organised, 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.



www.icos-ri.eu

ISBN 978-952-69501-1-2