ICOS

INTEGRATED CARBON OBSERVATION SYSTEM

Progress Report
2015–2017

CONTENTS

Foreword

IT'S LIKE THE WEATHER: the greenhouse gases in the atmosphere don't know any borders between countries. They travel in the atmosphere with the winds, even thousands of kilometres. No wall can stop them and they may impact climate far away from the regions of their origin. In order to understand these gases, their sources, transport, sinks, and finally their balance, it is essential to have standardised in situ observations with broad geographical coverage. ICOS provides this measurement network in Europe, 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 1990's, so the journey has been a very long one, indeed, and as time went by, it was never boring. Pursuing the common goal has driven the community forward, often with incredible patience and will when facing difficulties.

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

This report summarizes the journey so far, with a strong focus on the time since November 2015 when ICOS ERIC came into existence. Now, after roughly two years of ICOS ERIC's existence, it's time to stop and linger for a moment and take a look at how far we have come in our journey. To know the current position is essential for planning the future.

A personal remark at the end of this foreword: being on the bridge as 'captain' during the past four years has been an awesome experience. Seeing the progress of ICOS makes me proud of the community I have been part of. I want to cordially thank everybody who helped to build our Research Infrastructure and I am looking forward to going on in this constructive and very special ICOS spirit.

Werner Kutsch
Director General

1 What is ICOS?

The Integrated Carbon Observation System (ICOS) is a distributed European-wide research infrastructure producing high-precision data on greenhouse gas concentrations in the atmosphere, as well as on carbon fluxes between the atmosphere, the earth and oceans. ICOS produces standardised and open data from 134 measurement stations across 12 European countries.

ICOS provides data for the science to understand the Earth system. Scientific knowledge on carbon emissions, sinks and trends advances the fulfilment of the UN Sustainable Development Goals and EU Societal Challenges, especially the ones concerning climate change. It also supports efforts to comply with the COP23 Paris Agreement resolutions. ICOS also actively communicates the science-based knowledge towards society and seeks to provide information that is relevant to climate action and decision making.

ICOS' mission to understand the carbon cycle and to provide necessary information on greenhouse gases, places ICOS into a framework of other international climate organisations, such as United Nations Framework Convention on Climate Change (UNFCCC), World Meteorological Organisation (WMO), The Group on Earth Observation (GEO) and Global Climate Observation System (GCOS). In these frameworks ICOS has developed strong co-operation with similar research infrastructures around the globe. All these have a common goal to establish global standards for observations as well as open, accessible and interoperable data in order to ensure optimal services for societies in their efforts to mitigate climate change.

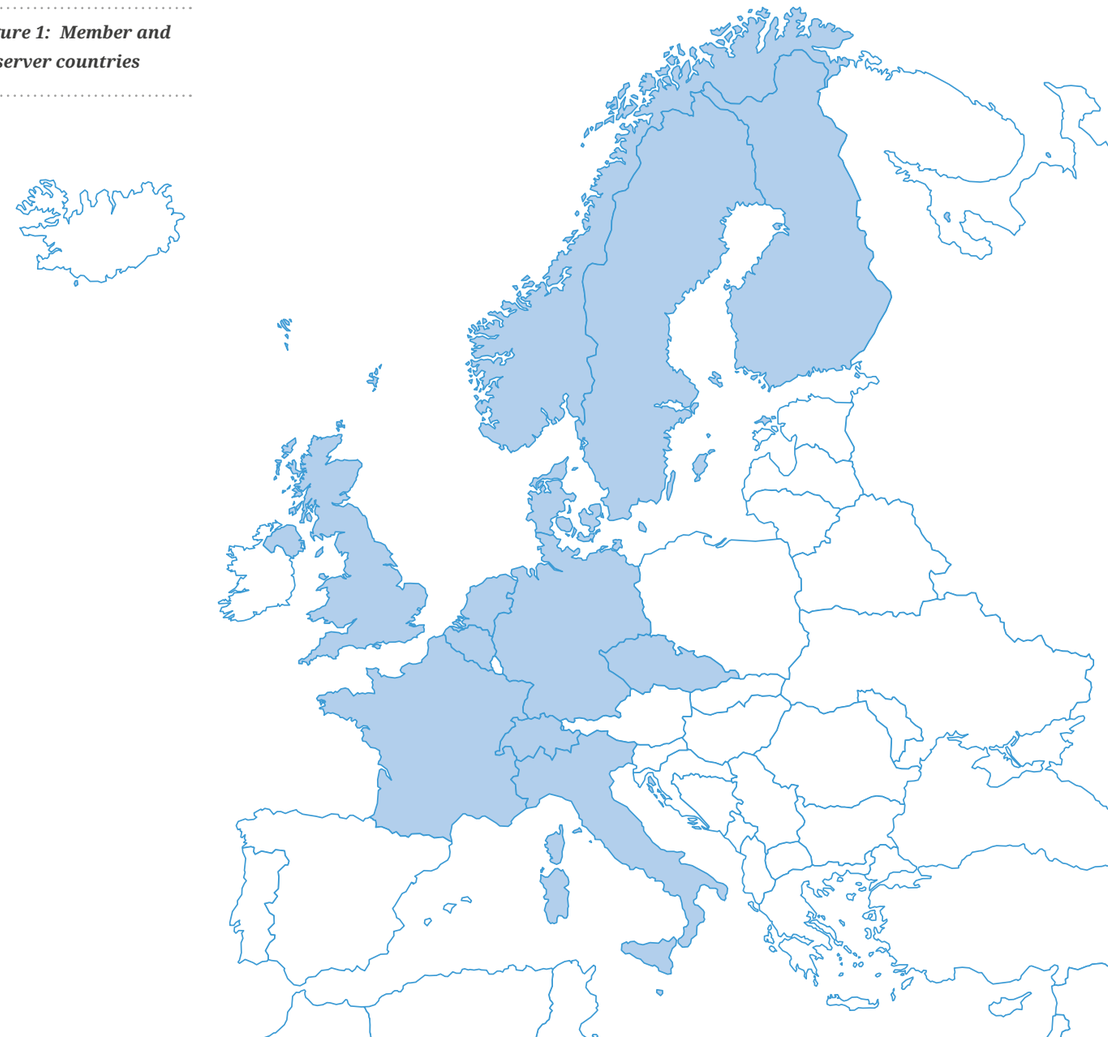
ICOS COMMUNITY

The ICOS community consists of more than 500 scientists, both in the current member countries and beyond, who participate in ICOS related work and operations. They design, build and operate ICOS stations, but even more importantly, process and use the ICOS data while fitting complex models on it. They publish scientific papers, participate in workshops and conferences, and develop new measurement methods that may become operational within ICOS in the future.

The community, as ICOS itself, has three fields; ecosystem, atmosphere, and ocean. Each of these three ICOS communities also has strong connections to colleagues and operators outside ICOS, which in turn increases the value, and also the influence of ICOS.

The size of the ICOS community can also be described as a number of scientific organisations participating in the research infrastructure: currently over 70 renown universities or institutes. ICOS has a high scientific standing, as evidenced by the participating universities and institutes, of which five have been ranked in top 100, and 15 in the top 200 in the world.

Figure 1: Member and observer countries

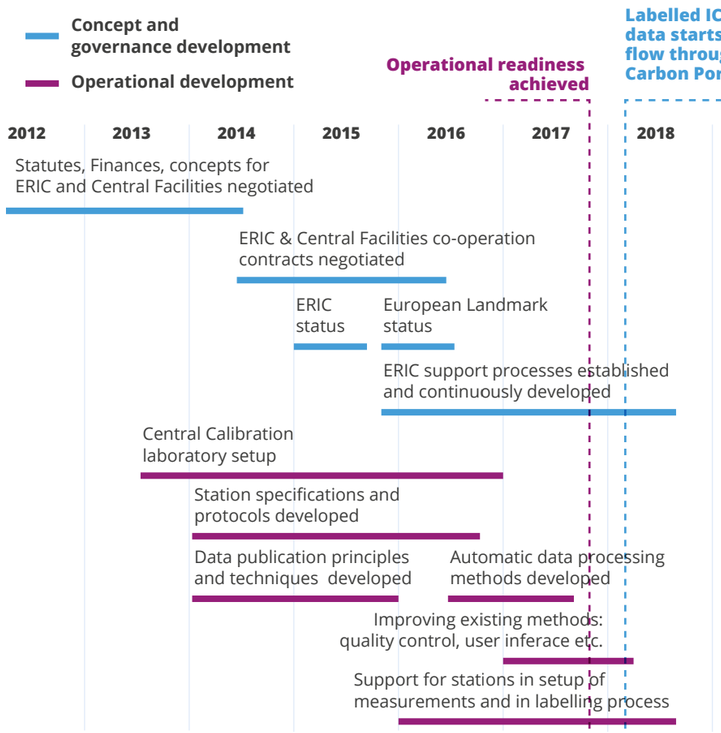


Key milestones of ICOS' journey

ICOS features a unique standardisation concept for greenhouse gas observations, covering both measurements on the stations, and the handling of data. The development of ICOS has been a science-driven effort involving hundreds of scientists and required several years of hard work. The graphics in these pages offer a summarized view on the development from 2015 to mid-2018.

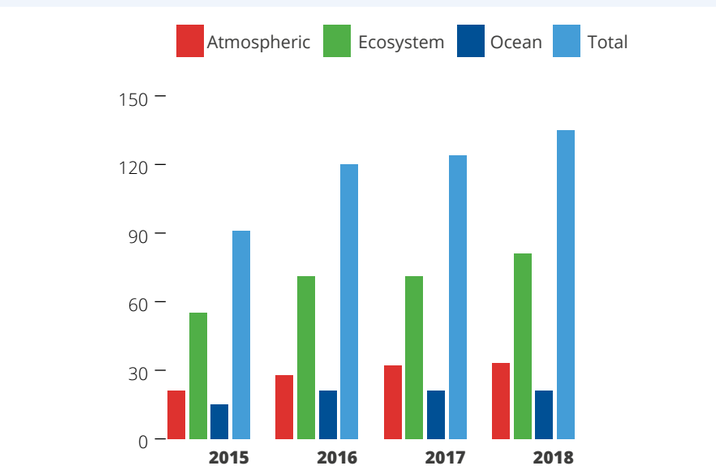
ORGANISATION AND OPERATIONS DEVELOPED

Negotiating statutes, financial structure and co-operation agreements took years, and involved mixed teams of law, administration, financial management and science specialists in universities, institutes and ministries. After the key elements were in place, the scientists focused on establishing operational requirements and principles, such as station protocols and data publication principles. A third phase started in 2016, when the community concentrated on further developing technical capabilities and on station labelling.



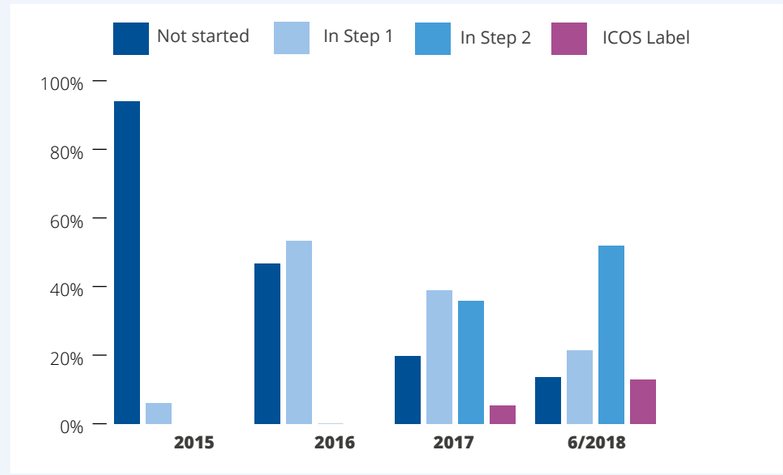
NUMBER OF STATIONS GROWING

ICOS stations are located across the Europe, and their number has grown from 90 to 131 since the end of 2015.



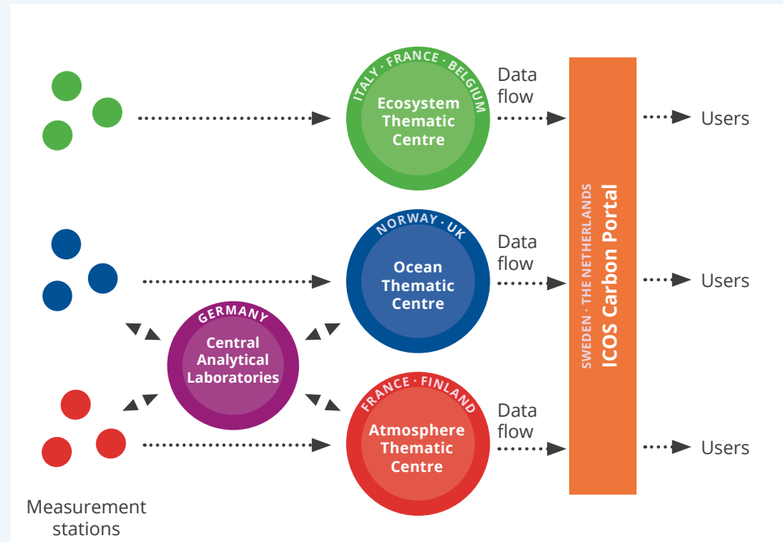
PROGRESS IN STATION LABELLING

The high quality of ICOS data is guaranteed with an extensive standardisation and compliance assurance process that the stations go through. To receive the ICOS certificate, i.e. the label, a station must pass a 2-step process. Stations usually work about three months for each step.



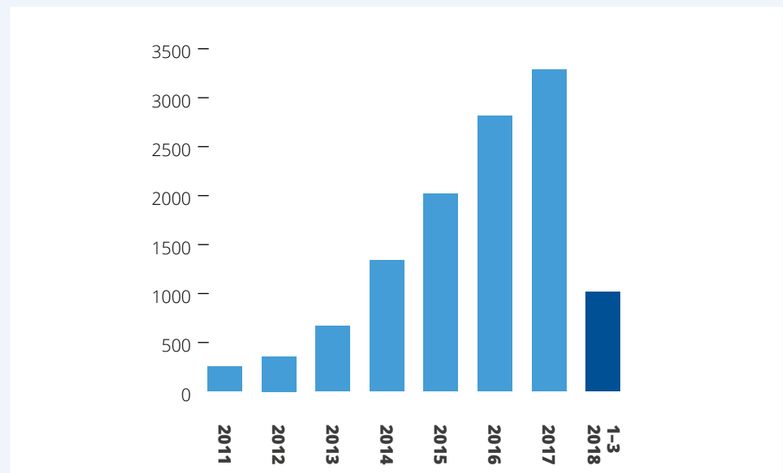
ICOS DATA IS STANDARDISED AND OF HIGH QUALITY

The open high-quality ICOS data is produced with standardised methods and published in a way that allows tracing each data object back to its station. ICOS has strict control over the whole data lifecycle so that the whole process is documented, transparent and reproducible.



ICOS IMPACTS TO SCIENCE AND SOCIETY

The publication and citation trends of ICOS data go strongly upwards, showing the increasing use of ICOS data in science.



2 Organisation and Governance

ICOS is a distributed research infrastructure, which means the key functions, including their funding, are shared and distributed among the member countries.

ICOS operations are coordinated by ICOS European Research Infrastructure Consortium (ERIC), a specific legal entity for European research infrastructures created by the European Commission. ICOS ERIC consists of the Head Office coordinating the RI operations, and of Carbon Portal collecting and distributing ICOS data.

ICOS ERIC is governed by its General Assembly. The Assembly is represented by the Director General, who is responsible for the implementation of its decisions and leads the ERIC.

The basis of operations is the standardised ICOS station network of 134 stations. It consists of atmosphere, ecosystem and ocean stations located across Europe and beyond. Each of these three fields has its own Monitoring Station Assembly (MSA), where the leaders of the stations, i.e. Principle Investigators (PIs) are represented, discussing station and network related issues.

ICOS RI comprises, four Central Facilities: Atmosphere, Ecosystem and Ocean Thematic Centres, and the Central Analytical Laboratories consisting of Flask and Calibration Laboratory and the Central Radiocarbon Laboratory. These Central Facilities coordinate and lead operations within their fields and process the data coming from the sites. They also have key roles in specialised analyses, metrology and technology watch. They are hosted by universities or research institutions in the member countries.

The representatives of Central Facilities and MSAs also form a high-level advisory body called Research Infrastructure Committee, which advices the Director General and the General Assembly on scientific and organisational matters concerning the RI.

The General Assembly has also established two external bodies to give advice on scientific and ethical matters: Scientific Advisory Board (SAB), and 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, advise ICOS ERIC on the objectives to achieve the scientific goals of ICOS RI,

Figure 2: ICOS governance and structure

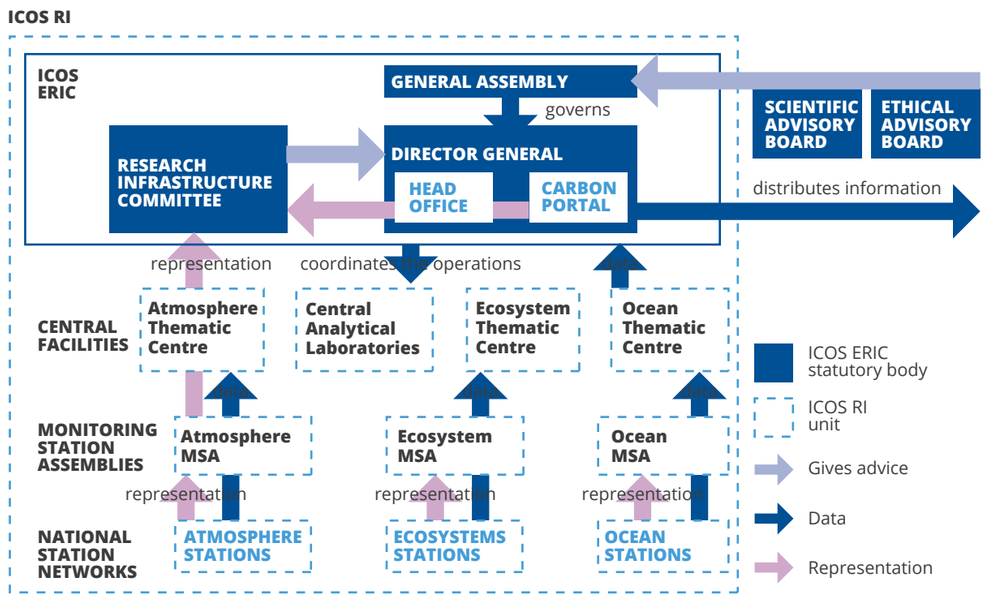
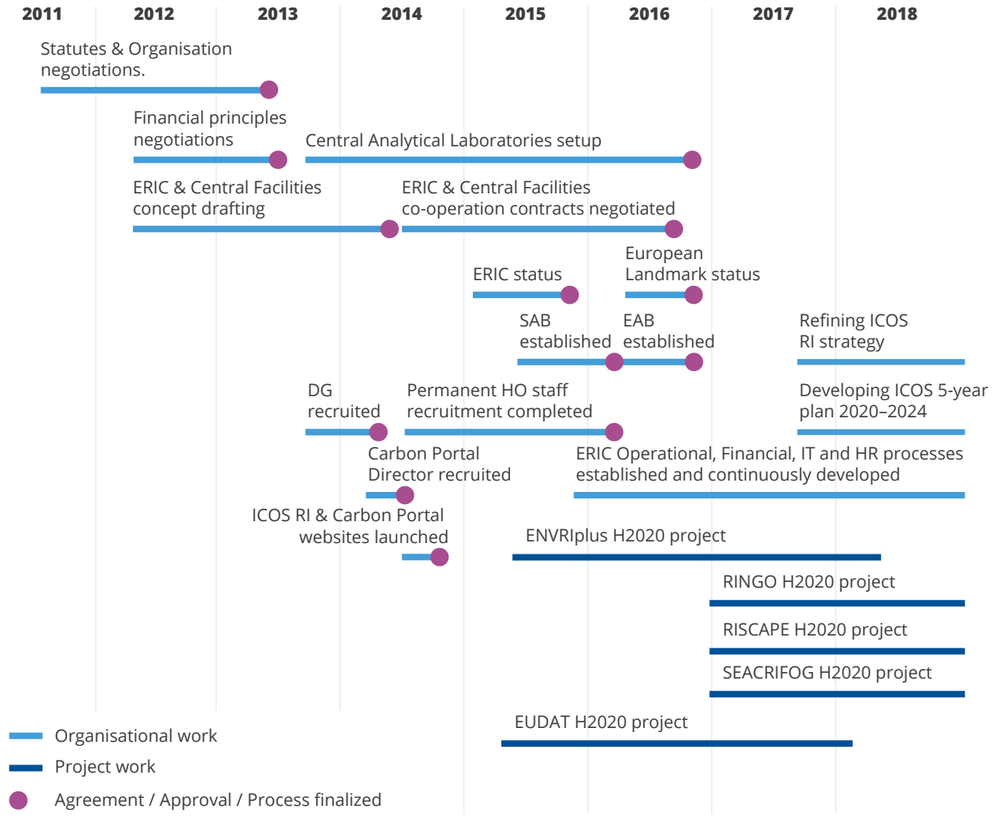


Figure 3: Organisational milestones towards ICOS ERIC



Establishing ICOS required long negotiations between ministries, funding organisations and scientific host organisations within the founding countries.

provide programmatic support by commenting on the overall science plans and directions, and analyse the scientific results and impact of ICOS RI. The role of the EAB is to advise and periodically report on ethical issues, such as scientific ethics, data related ethical issues, discrimination issues, or any kind of conflicts of interests.

JOURNEY TO SUSTAINABLE RESEARCH INFRASTRUCTURE

To establish a sustainable and efficient research infrastructure, several working groups started their work already in 2013. The groups coordinated and negotiated the statutes, organisational and financial structures and the data policy of ICOS. This management structure has been further developed after the establishment of the ERIC and has become a role model for other, more recently established distributed environmental research infrastructures, where imprints of the ICOS structure can be found in many constitutional documents.

Milestones towards an ERIC

The transition phase between the preparatory phase (FP7 project 2008–2013, led by Philippe Ciais) project and the establishment of an ERIC is often called “the valley of death” due to a lack of resources. Early support by Finland as a statutory seat of ICOS, and Sweden as a Carbon Portal host, allowed to set up a transition team lead by Timo Vesala as interim director. It enabled recruitments of Werner Kutsch as Director General already in March 2014 and Alex Vermeulen as Director of ICOS Carbon Portal in June 2014 – long before the ERIC was established. However, national governments and host institutions supported ICOS on all levels to build up the infrastructure during the transition period. It took one and a half years from the end of the (extended) preparatory phase project until ICOS ERIC was finally founded by the EU Commission in November 2015.

With ICOS ERIC coming to life, it became necessary to establish and further develop its administrative, financial, and human resources management, efforts that were – as often happens – underestimated. Negotiations with local authorities about the legal status of ICOS ERIC and respective consequences e.g. on VAT exemption were complex. Being an employer and recruiting new people in two countries – Finland and Sweden – created some administrative challenges as well. Between 1.1.2016 and 31.12.2017 the Head Office personnel increased from five to 12 full-time positions, partly with fixed-term contracts due to project funding.

During 2016 and 2017, ICOS ERIC Head Office established internal staff rules, regulations for recruitment, travelling, and personal development, as well as descriptions of the roles of the employees and financial processes, for example, in regards to the invoice approvals and management of EU projects.

The Scientific Advisory Board was established in 2016 to monitor the scientific quality of ICOS RI. The Ethical Advisory Board was established in 2016.

Implementing Central Facilities

The Central Facilities were implemented and further developed during the interim phase and the first years of ICOS ERIC. Building a legal structure through cooperation agreements between ICOS ERIC and the respective host organisations of the Thematic Centres including rules and templates for financial reporting required large efforts between 2014 and 2017. Finally signing these agreements culminated several years of negotiations and preparations.

The basic organisational philosophy of ICOS as a distributed research infrastructure, is consolidated in these cooperation agreements. While the tasks are clearly defined and agreed upon between ICOS ERIC and the Central Facilities, the basic management and internal distribution of the work is organised by the host institutions, and employment practices are carried out according to the respective institutional practices. Financial governance follows the similar approach: the host institutions have their own responsibility but have to comply with common rules and are monitored by ICOS ERIC.

The Thematic Centres became stepwise operational between 2013 and 2017. The Central Analytical Laboratories set up their analytical capacities based on national funding. This included defining tasks and roles of the staff, as well as recruiting and training the personnel.

Establishing National Networks

The construction of the ICOS station network did not have a distinct starting point since major part of the ICOS National Networks have been built using existing stations, of which some have been already working for decades. Only a relatively small number of new stations were erected completely from scratch. However, existing stations had to be re-equipped substantially to comply with the new ICOS standards.

In addition to the ICOS ERIC and Central Facilities' negotiations, the establishment of ICOS National Networks also has required a significant amount of negotiations usually resulting in cooperation agreements at national level. The respective negotiations took up to three years. In practice, the ICOS related local cooperation is being led and carried out by a national coordinator who also serves as Focal Point towards ICOS ERIC. In many cases, an assistant has been nominated to share the workload and to take care of practical matters. These tasks are usually performed as an in-kind contribution by one of the participating institutions.

Up until now, altogether 12 ICOS member and observer countries have set up a ICOS National Network. Additionally, several countries have expressed their interest to join in ICOS and contribute to the ICOS National Network with existing or planned stations.

Most of the National Networks started their operation in 2015 and have since organised a significant number of national or regional scientific events, such as conferences, training courses, workshops or annual meetings combined with seminars. In 2017, over 300 persons participated in these ICOS related national events.

Figure 4: Number of countries, growth

31st Dec 2015	31st Dec 2016	31st Dec 2017
9	12	12

TIMO VESALA,
Focal Point of ICOS Finland National Network, Interim Director General of ICOS between 1.1 2013 – 28.2 2014
Academy professor at the University of Helsinki, Faculty of Science, Institute for Atmospheric and Earth System Research/Physics

"The preparatory face to establish ICOS required a lot of negotiations, protocols and agreements between universities and countries during the years. Many of these negotiations were official meetings involving both scientists, civil servants and lawyers from various governmental institutions. There were also a lot of unofficial discussions, for example between scientific colleagues from different countries.

The responsibilities and also the locations of the Head Office and the Central Facilities were a significant area in the discussions, and the data flow was initially defined already during this preparatory face. I remember the role of the Carbon Portal was also discussed, and suitable candidates for host countries and institutions evaluated. We had special working groups for statutes as well as for the budget structure. Reaching agreements required of course compromises from all parties.

In this long process of negotiations, I remember that finalisation of the tasks of the various working groups were always great milestones and achievements, as was the successful recruitment of the Director General. From my point of view the decision to locate the Head Office to Finland was also a highlight. Sometimes I felt that every single decision made in the negotiations was a reason for celebration, as at times it seemed we were proceeding really slowly, and even opened up once decided matter for re-negotiations. Having experienced all this, it was of course a major highlight when the ERIC was established, as it symbolically culminated all our work."

DARIO PAPALE,
Director, ICOS Ecosystem Thematic Centre
Associate Professor, University of Tucsia

"When the ICOS negotiations started in 2013, the topics, methods and people involved in the discussions were something completely new for me, they were really different from the research projects meetings and procedures that I'd done in the past. When now looking back, it was very interesting and eye opening, with so many countries, governmental representatives and politicians involved, and so many interests represented with the need to find common solutions."

"One interesting twist in the negotiations was the existence of ICOS Carbon Portal, as it was introduced rather late in the planning process because it was originally not envisaged in the ICOS Preparatory Phase FP7 project. Originally, I thought there was a conflict of competences between the portal and the thematic centres, and I was rather critical towards this risk and unclear organisation. However, the discussions that followed during the months got me convinced, that we should use the data processing power of one centralised unit. Currently the ETC is really relying on the Carbon Portal services and the collaboration is really good and has improved the quality of the work."

3 Financial structure

The overall budget of ICOS RI was EUR 24 219 443 in 2017. With an almost 70% share for the National Networks, the predominant part of the ICOS funding supported basic data production at the 135 stations, while 22% has been used for the Central Facilities, and 9% for ICOS ERIC.

ICOS financial concept follows the general policy of the European Strategic Forum for Research Infrastructures (ESFRI): research infrastructures (RI) receive stable and sustainable funding from their member countries to ensure their operations. Additionally, new developments and innovation are supported through funding by the European Commission's Framework Programmes for Research and Innovation (the current program named 'Horizon 2020').

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

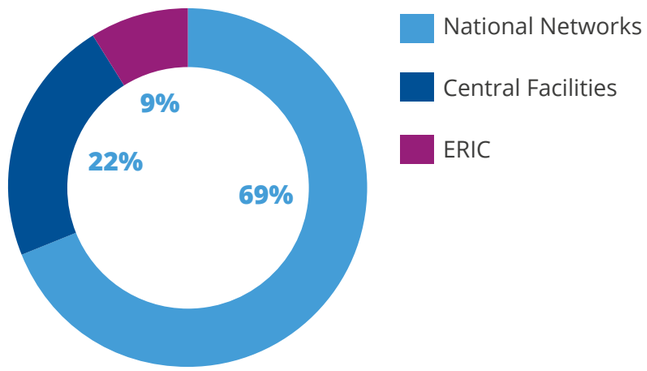


Figure 5: Of the total ICOS RI budget, almost 70 percent was used by the National Networks for data production.

4 From a network of scientists to a research infrastructure

The story of ICOS is, in essence, the result of hundreds of scientists from all over Europe working together and developing a totally new, standardised concept for greenhouse gas observations for science and climate action.

The ICOS standardisation concept covers both the station specifications as well as data handling methods and is the key innovation of ICOS. It has been a science-driven community effort that lasted several years. The participation of the scientific community has been crucial for the acceptance of and compliance to the standards. As fully operational European Landmark infrastructure, ICOS offers the following key features:

- Standardised measurement stations with sufficient coverage
- Standardised ways of handling the data and the data life cycle
- A labelling process to ensure the two points above are realised
- Common data licence and data attribution

Each of the topics above, including the developments achieved, are described in the following chapters.

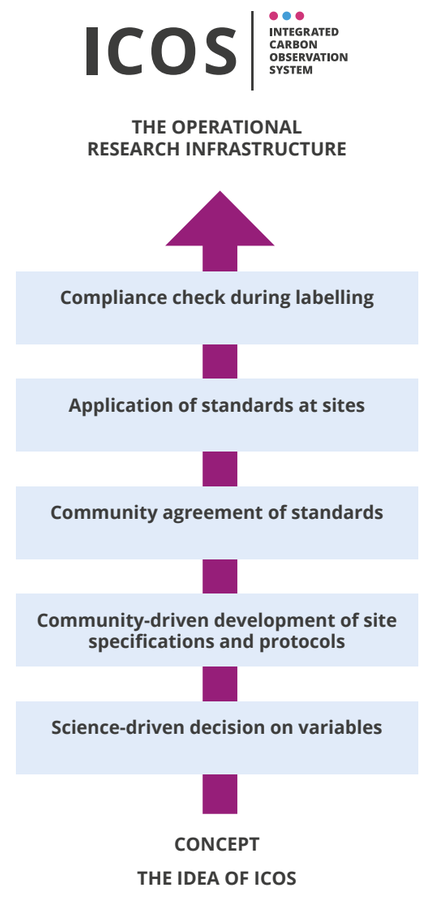


Figure 6: ICOS' journey from concept to operational research infrastructure.

BUILDING A STANDARDISED MEASUREMENT STATION CONCEPT

The types of stations and the methodologies differ between the three ICOS domains: the way and the conditions in which the measurements are conducted are completely different.

However, the stations within the same domain are strongly standardised, utilizing similar methodologies and equipment. The ICOS standards cover, for example, how and when to perform the measurements, such as taking samples or reading a result, how and when the equipment needs to be calibrated, and how data and quality are managed.

All labelled stations within a specific domain and station type will also have the same instrumentation installed in the same way, and they will also use exactly the same procedures for submitting the data.

Leonard Rivier, Director of the Atmospheric Thematic Centre, LSCE, describes the process: "There were three notions at the heart of creating ICOS: high precision, standardised and long-term. Highly precise measurement is needed to capture the background GHG concentration signal, which is weak in the atmosphere but covering large geographical areas. Standardised measurement enables researchers to inter-compare the different stations that are all measuring concentrations on the same international reference scale. Concentration difference between atmospheric stations is what is used to derive country fluxes from measured concentrations using inverse atmospheric transport models. Long-term records are key to quantify climatic trends and need guaranteed funding to avoid data gaps."

Atmosphere stations

The ICOS atmosphere community, Principal Investigators of the stations, and ATC developed the atmosphere station specification. ATC personnel performed most of the work and carried the final responsibility. The work took several years, with the first version of the station specification document being published in 2014 and the latest update in 2016. The full specification document is available on ATC web pages.

The atmosphere station specifications define the measurement objectives, sampling strategies, set up, protocols, calibration and standards, data management, and quality management in very detailed and practical way. In terms of measurement setup, criteria for station locations and variables measured as well as equipment requirements on the level of single sensors are defined. The calibration section of the document concentrates on maintaining the measurement validity and reliability through defining what, how, and how often the calibrations are done. It also describes the requirements for calibration equipment.

ATC has also constructed a metrology lab to test and benchmark atmospheric GHG analysers, and it is now operational. The benchmark is used even by industrial companies. Over 60 instruments have gone through the ICOS ATC bench for testing, creating a unique and extensive dataset. A synthesis of these tests was documented in a publication by Yver Kwok (Journal of Atmospheric Measurement Techniques, 8, 2015).The ATC metrology lab also performs technology watch with feedback toward companies to improve instrumentation for the benefit of the whole community.

In addition to the metrology lab, ATC has started a mobile lab that performs station audits throughout the ICOS atmosphere network. The mobile lab performs parallel measurement to the station thus assessing the

Photo: Mari Keski-Nisula

entire measurement chain at the station (collection, measure, data treatment).

In 2017, ATC development work has concentrated on automatic data processing methods and processes for the atmosphere data, as well as supporting the stations with the labelling process e.g. by giving continuous phone and e-mail support, and by writing various instructions and other documents. ICOS ATC in-house software was developed for station PIs to allow thorough quality control of the data, both automatically and manually. Tens of internal data products are generated daily for each station to assess the quality of the data in near real time. Special care has been put in the development of the software to ensure traceability of the data process. ATC also put into place a highly recognised training platform, tackling both metrology and data processing aspects of ICOS atmospheric measurements.

Ecosystem stations

The Ecosystem MSA and ETC developed protocols for the ecosystem sampling methods, observations and data processing for the collection of about 120 variables at the stations. The protocols have been developed in 17 different working groups, which were open to the whole scientific community, inside and outside ICOS. The ICOS Ecosystem protocols are currently published and will be proposed as an international standard. From the beginning, the ETC wanted to align the protocols with existing and ongoing initiatives.

"We invested a lot of time to have our data and the way it is organised, to be fully compatible with other data systems. To that end, we discussed and collaborated tightly with other data providers. For example, our way of reporting eddy-covariance at the ecosystem stations is fully comparable with other networks in the world, such as AmeriFlux or FLUXNET," tells Dario Papale who coordinates the ETC efforts to translate the protocols into concrete instructions, templates and processes.

In order to ensure data integrity as far as possible, the ETC and the Carbon Portal designed an automatic and direct data submission from the ecosystem stations to the Carbon Portal and a subsequent cloud-based processing by the ETC. In practice, this meant defining specific data formats that support the automatic transfer.

In the last two years, the ETC has also been heavily involved in the labelling of the stations, assisting the station PIs in building the best possible infrastructure and ensuring full compliance with the ICOS standard. This activity is still ongoing and it will be probably the main activity also in the next couple of years.

Ocean stations

The marine network consists of a variety of ships and fixed station installations covering the open ocean and coastal areas, and for this purpose the network is divided into four categories: Carbon-VOS, i.e. Carbon Voluntary Observing Ships; Repeat Sections on the open ocean, Fixed Stations located at open ocean and coastal areas; and Flux Towers that are at coastal areas.

For each category, ICOS defines two classes of marine stations according to the set of parameters measured. While Class 1 marine station manages a list of 4–13 mandatory core measurements, the number depending on station category, Class 2 marine station operates only a subset of these. The requirements for data quality, however, are the same for ICOS Class 1 and Class 2 stations, VOS lines and research vessels. Every category also includes a ranked list of desirable additional parameters.

In 2016, OTC defined the data quality criteria for all data going to be distributed through Carbon Portal. To help with the quality assessment, OTC started in 2016 to develop a specific software service to aid with the quality assessments during the labelling process. This has been tested and finalised in 2017. The software performs calculations and automatic quality checks to provide summaries of data quality, which are used by expert reviewers when judging the data.

Central Analytical Laboratories supporting in data calibration, analysis and quality control

The role of the Central Analytical Laboratories, CAL, is to ensure the accuracy of ICOS atmospheric measurement data. This goal involves, for example, provision of reference gases for calibration of continuous in-situ measurements performed at the monitoring stations; the analysis of ancillary parameters in air samples taken at the ICOS monitoring stations; maintenance of sampling containers; development of sampling equipment; support of quality control activities.

In 2016, the readiness of the CAL proceeded significantly: The reference gas production and calibration for the ICOS atmosphere network were developed and operational. CE compliant air sampling equipment was developed, and the first units constructed and delivered to the atmosphere stations.

In 2017, the developed quality control check was implemented in the automated data processing for all calibration measurements, and quality control evaluation was implemented for uncertainty assessment for calibration measurements. Both of these developments increase the reliability and validity of ICOS data.

The Central Radiocarbon Laboratory delivered high-volume integrating carbon dioxide samplers to all ICOS Class-1 atmospheric stations and analysed more than 500 radiocarbon samples from all over Europe. These results form the basis for estimating the mean fossil fuel carbon dioxide contributions at the sites.

5 Standardised ways of handling data and the data life cycle

Data handling is the key for the high ICOS data quality. ICOS has created a transparent, documented and reproducible process throughout the data life cycle: from from the generation of the data at the station, via the Thematic Centres and the ICOS Carbon Portal to the user.

DATA PRINCIPLES DEFINED

The general principles on handling and distribution of ICOS measurement data and products were agreed very early in the planning phase.

"Although the FAIR as an acronym did not exist at the time of planning the Carbon Portal in 2012–2013, we had a clear view that the data should be easily Findable, Accessible, Interoperable and Reliable, i.e. FAIR," says Alex Vermeulen, Director of ICOS Carbon Portal.

In practice, the FAIR principles mean giving the user sufficient tools to understand the meaning of the data before and after downloading it. For this purpose, ICOS Carbon Portal utilizes linked open data technology, which is a relatively advanced technology within the field of data management. It allows ICOS to distribute the data through links that the user can just click to see and even download the data. It also makes the machine-to-machine communication of data possible. Metadata and other descriptions are visible, and the user should be able to preview the data before downloading. Carbon Portal developed and installed these functionalities from 2014 through 2017.

As its data licence format, ICOS has decided to use Creative Commons Attribution 4.0 International (CC4BY), which 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 with the licence upon downloading the data – this feature has been developed and implemented in 2017, together with data usage tracking and counting the number of downloads.

To attach the data ownership, ICOS utilises Digital Object Identifiers, i.e. DOIs and Persistent Identifiers, PIDs. These uniquely identify each data object and can be cited e.g. in scientific publications. The PID is being created automatically and immediately at submitting the data, utilizing mathematical encryptions to ensure the validity of the data. The PID creates a www-address (URL) to a landing page where the metadata can be viewed or accessed, either by humans or machines. Accessing the link will trigger the use license acceptance check. The usage is counted at the download.

The whole process guarantees that the original data and downloaded data are exactly identical, 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 ICOS Carbon Portal.

ICOS DATA LIFE CYCLE

ICOS data life cycle includes all the steps from collection, management and preservation of the data to the point when data is published and used. In short, the data life cycle process describes who is handling the data at a particular point in time, and what is being done to it. The ambition of ICOS is to have strict control of the whole data lifecycle so that the whole process is documented, transparent and reproducible. This means that when verification, corrections or updates of the processing are required, the whole processing chain can be repeated from raw data to the final product using the stored metadata.

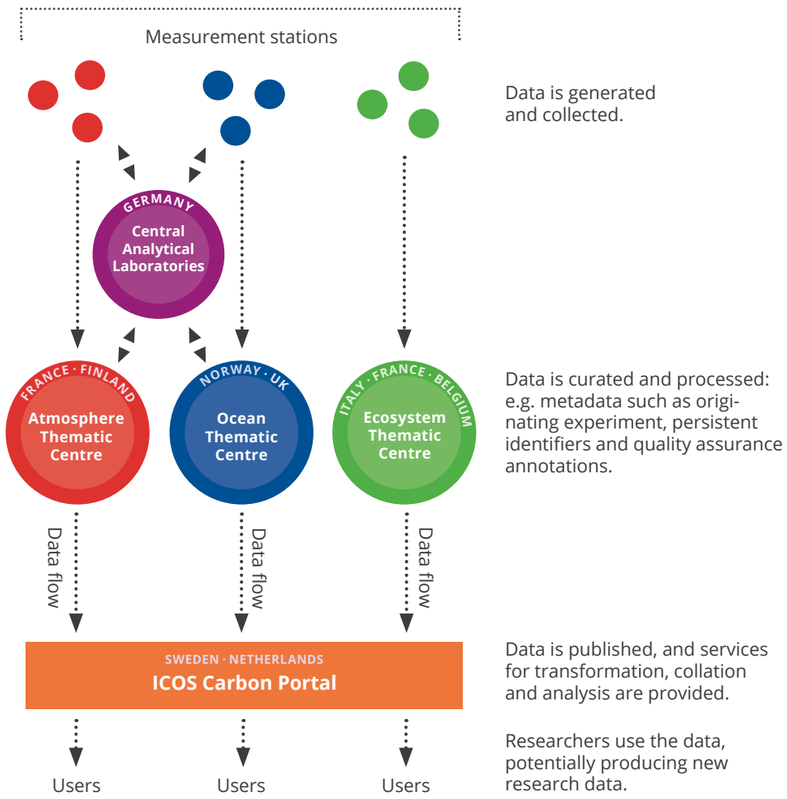


Figure 7: ICOS data production process

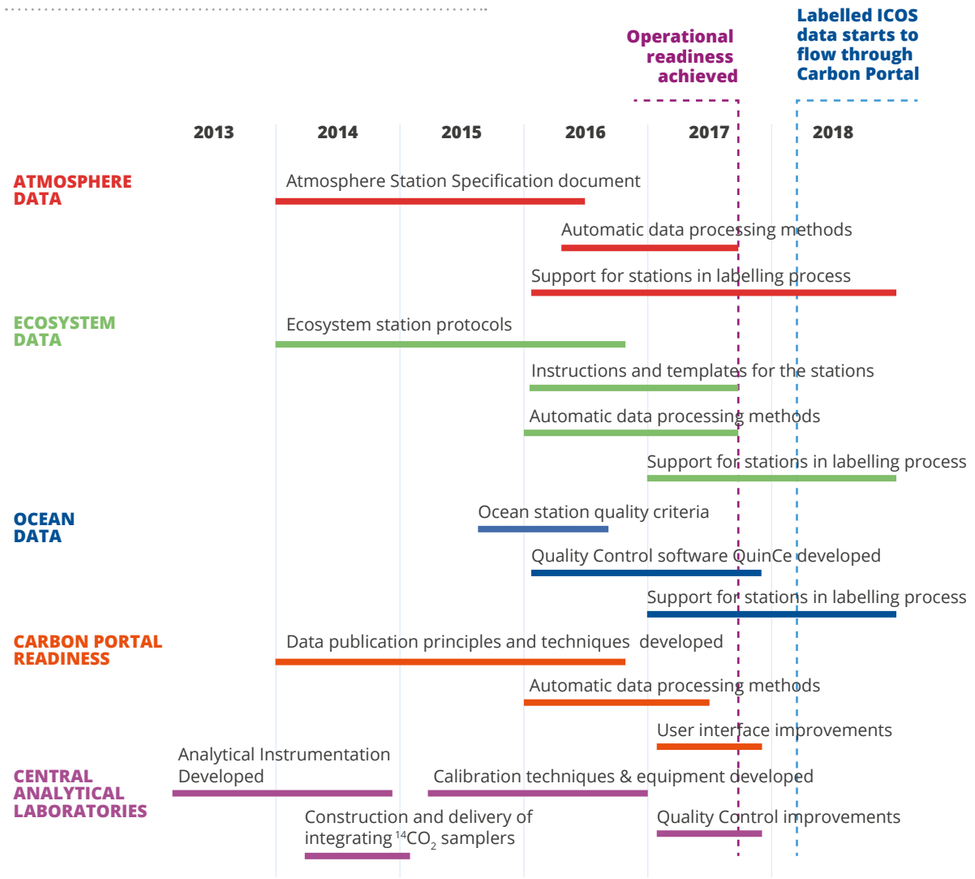
The data flows from the measurement stations through the Thematic Centres to ICOS Carbon portal, where users can access it.

The ATC, ETC and OTC data life cycle processes reflect the respective Thematic Centres, as each domain has slightly different traditions. In the ecosystem domain, practically no commonly agreed processes existed for the raw data at the time of starting the ICOS planning. Thus, ETC and Ecosystem MSA had a possibility to design a process, where the data is being transmitted directly and automatically from the stations to the Carbon Portal, from which ETC and also scientists can then easily retrieve, process and use the data for scientific purposes.

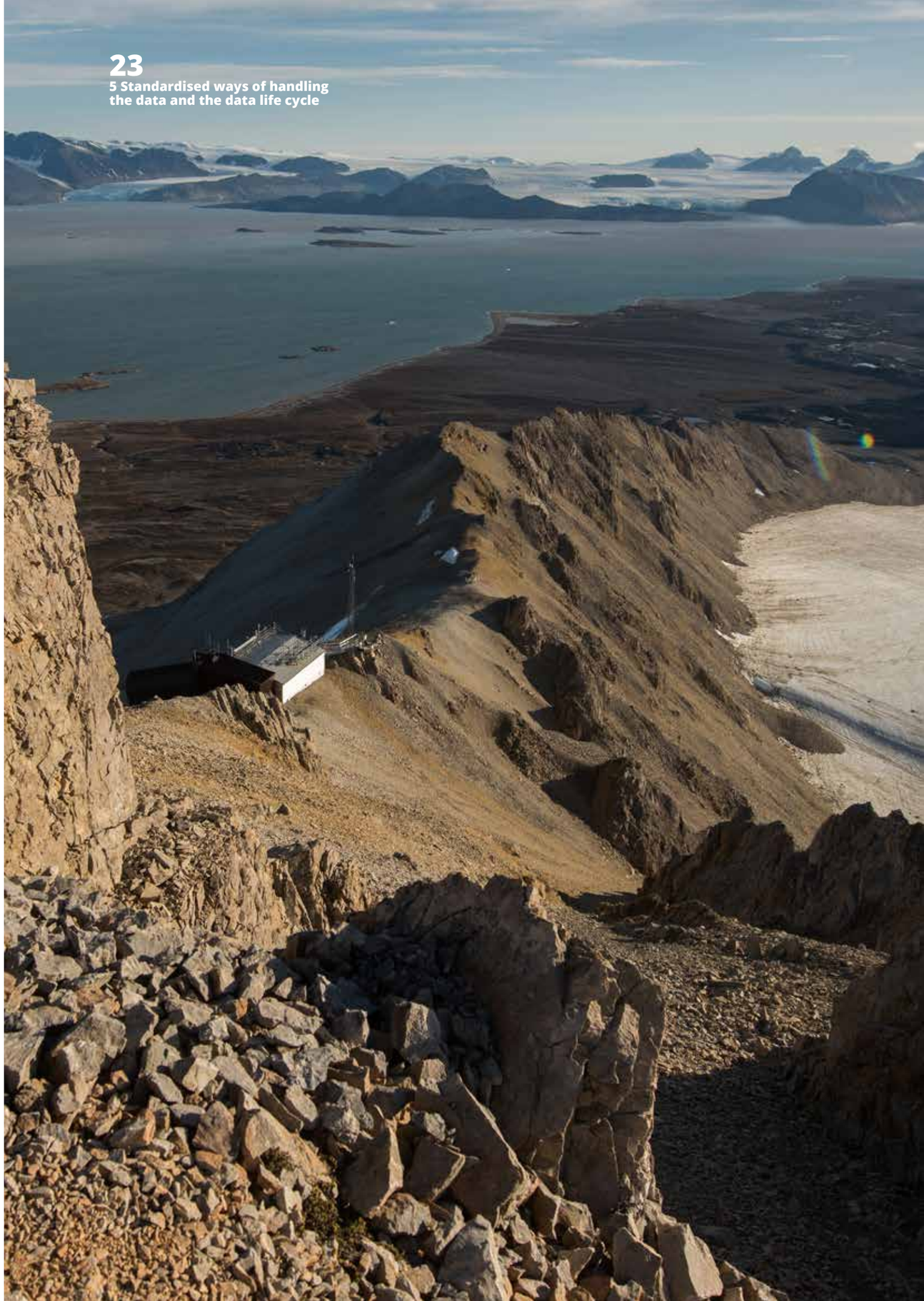
This process has several benefits, according to Dario Papale, Director for ETC:

"Automatic data submission allows us to have near real-time data, to have fresh measurements every day. It also minimizes the risk of human errors in the process and allows us to fix possible code errors afterwards: faulty data caused by a particular error can be corrected afterwards. Of course, human control is probably the tightest, but machine-to-machine is more robust and more documentable. Additionally, having

Figure 8: ICOS Data life cycle development – Progress



The station specifications and protocols ensure that the stations produce and treat the data in the same way. This is a fundamental element to the standard high quality of ICOS data.



expert people who organise the data and make it available for the users in the best possible way improves the quality of our work. Finally, it is wise to concentrate the data processing and maintenance competencies and systems in one place.“

In the atmosphere and ocean domains, the station data is initially received at the respective thematic centre and then submitted to Carbon Portal to mint the PID and store the data in the trusted repository.

ATC has defined the requirements for data processing and archiving, for various kind of metadata needed and for data quality control to make sure that the data received is of good quality and is treated correctly. The ATC data process has been published in Hazan et al. AMT, 9, 2016.

OPERATIONAL READINESS ACHIEVED IN 2017

All data and metadata produced at the stations are published dynamically and instantly and can be retrieved through persistent identifiers (PID), that are minted at ingestion.

The complete basic functionality for ingesting and publishing the ICOS data, including checking of the licence and usage tracking, has been finalised and in operational use since summer 2017. At the end of 2017, all thematic centres were successfully connected to the Carbon Portal data ingestion engine and used it operationally.

Atmosphere: Since summer 2017, atmospheric data has been ingested automatically from ATC, for the 10 stations that thus far have proceeded to step 2, for those instruments that it’s possible. The rest of the stations, i.e. 20 in total, are sending their data through ATC to Carbon Portal.

At the end of 2017, ATC station data made up 3200 of the 3900 ICOS data objects in the portal. Test versions of advanced ATC data products have also been submitted, although not yet published.

Ecosystem: In May 2017 a simplified interface was developed to ingest raw data directly from the Ecosystem field stations through the dataloggers used on the stations. The new automatic data ingestion was taken into operational use at the end of 2017 by ETC and in January 2018 by labelled ETC stations.

At the end of 2017, the Carbon Portal held just under 10 000 data objects, of which 3900 are labelled as ICOS data. This amount of data objects will start to grow quickly when the stations achieve Step 2 in the said process.

Ocean: In May 2017 the Ocean Thematic Centre ingested automatically 941 checked data objects from ship cruise data. This data is part of the latest SOCAT product and originates from the data sources that will be included in ICOS. This data is labelled in the store as pre-ICOS (and thus non-ICOS) data.

ADVANCING OPEN SCIENCE AND OPEN DATA

ICOS, and especially Carbon Portal, carries out extensive work in the H2020 projects that are beneficial to ICOS with regards to data management and computationally intensive science, (eScience), links to EUDAT and the other e-infrastructures that will play important roles in the upcoming European Open Science Cloud. ICOS is one of the early adopter communities that were invited to the EUDAT2020 project to take up the cloud technologies designed as the B2-suite that will now form the core of the CDI (Collaborative Data Infrastructure), serviced in the European Open Source Cloud. ICOS is also being represented in the Group of European Data Experts (GEDE).

ICOS’ efforts, in terms of open data, have been noticed widely. This is evidenced by two ICOS employees, Margareta Hellström and Ari Asmi, being awarded as European Data Champions by SPARC Europe, an international organisation advocating the open science and open access to data.

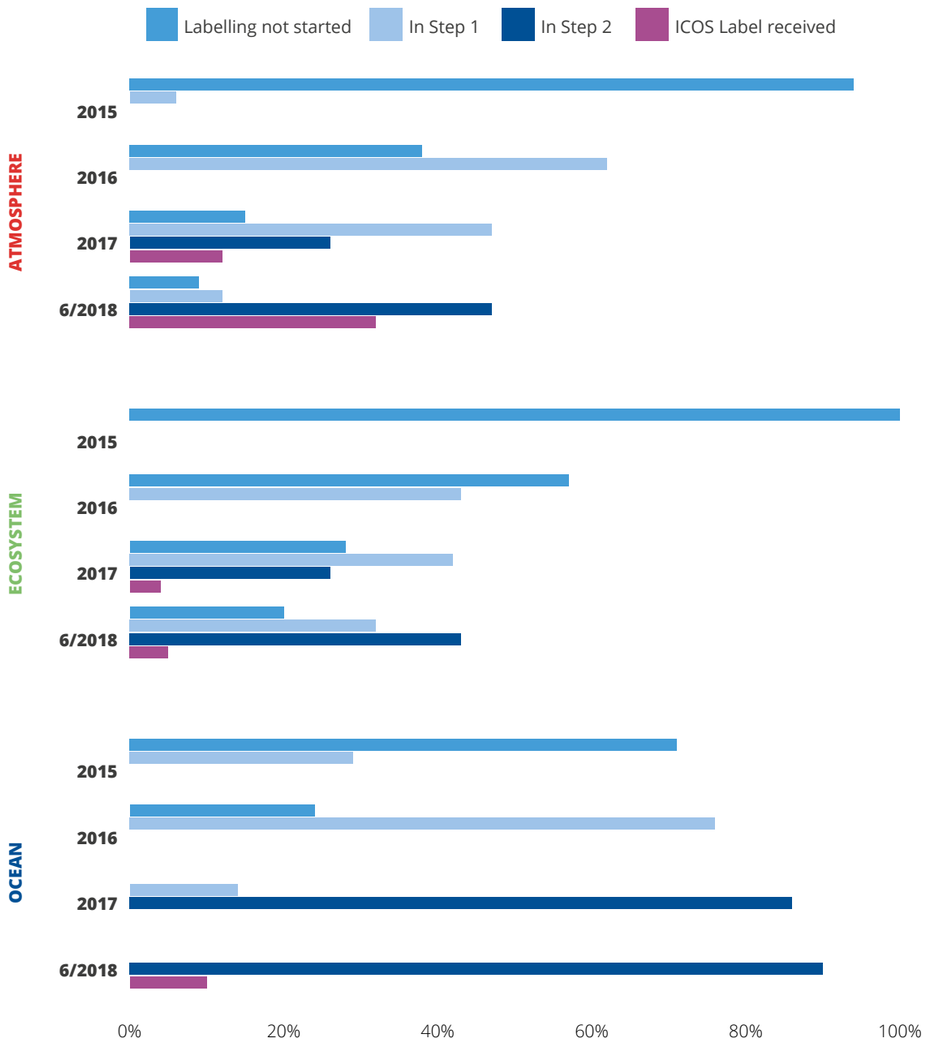
6 Development of the station labelling process

Compliance of the stations to the 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 with tight criteria.

To guarantee ICOS data reliability, each station has to fulfil all the ICOS criteria set, both for the stations and for data production. Therefore, ICOS has developed a labelling process to help station leaders (Principal Investigators, PI) to proceed in the station’s standardisation process. Once the station fulfils all the criteria set for an ICOS station, it receives an ICOS label to show that the data produced is indeed as reliable as required.

In 2016 and 2017, an important effort of Central Facilities, MSAs and National Networks has been the station labelling process. It consists of two sequential steps. The Step 1 comprises of the overall evaluation of the site, location of the measurement tower, and other characteristics, which are evaluated by the Thematic Centres. After the approval of the station evaluation in Step 1 by the Director General, the approved station is eligible for starting Step 2, in which a thorough analysis of the compatibility with the ICOS measurement protocols and standards, measurement setup, data transfer and data quality is performed. Finally, the General Assembly approves the station on the basis of the evaluation report prepared by the Thematic Centre and the recommendation by the Director General. The Thematic Centres control the process and support the station PIs to fulfil the requirements for ICOS stations. Thematic Centres also provide support for new incoming stations in the planning phase. The progress of the labelling is monitored by the RI Committee and can be followed transparently through the dedicated interface at the Carbon Portal.

Figure 9: Progress of stations in the labelling process



The high quality of ICOS data is guaranteed with an extensive standardisation and compliance assurance process, with domain-specific requirements. To receive the ICOS label, a station needs to pass a two-step process, with each step requiring about three months of work from the stations.

At the end of 2017, altogether 7 stations were labelled. Furthermore, 39% of all the stations were in Step 1 evaluation process, 36% in Step 2 evaluation process and 20% of the stations had not yet started the labelling process. The number of stations in the various stages of the process is visualized in figure 9 above.

7 Building a European station network

ICOS countries have together built a measurement station network consisting of 134 stations across Europe and beyond. This network enables science that provides knowledge through observations.

To gain a representative picture of the greenhouse gas balance in Europe, including emissions, sinks and transport, ICOS must have a sufficient coverage of stations across Europe and even in the adjacent regions.

This has several practical implications. Firstly, ICOS must have a sufficient number of atmosphere, ecosystem and ocean stations for its main geographical focus area in Europe; secondly, the number and locations need to be well chosen based on scientific and logistical arguments; and thirdly, these stations need to be situated in suitable geographical locations.

Geographically, the station network would ideally cover Europe from the Northern sea areas to the Southern Mediterranean, including North Africa, and from West to East including Eastern European countries outside the EU. Progress at this front is very dependent on political decision making. However, three new countries have joined ICOS since the end of 2015: Denmark, UK and the Czech Republic, bringing altogether 20 new stations to the network.

The network density increases also through existing member countries bringing in additional existing stations, as for example Denmark has done, or building completely new measurement stations, such as the atmosphere station *Křešín u Pacova* in the Czech Republic and ecosystem station Hurdal in Norway.

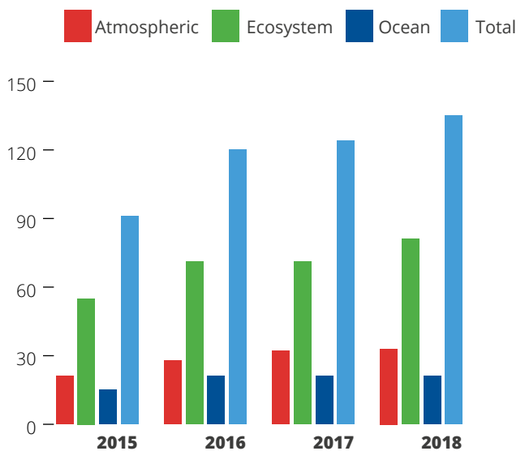
ICOS has only limited means to design an optimal network in terms of station locations or building new stations, because such decisions are made by the individual member states that operate and fund the stations. However, the National Networks always have the possibility to discuss and consult with the Thematic Centres and the Carbon Portal in order to find an optimal place for a station also considering the network.

The current (atmospheric) station network was originally designed to monitor the European background signal, distant from strong local human-induced signals. Most of the existing stations have been chosen at such locations more than 10 years ago. However, future measurement needs might require additions to the network also closer to hot spot areas, e.g. of fossil fuel CO_2 emissions; a design that allows to improve the network towards a more versatile network is now being developed for example within the RINGO project.

The parameters measured at the stations vary. For example, Class 1 and Class 2 Atmosphere stations have different requirements in terms of the number of measurement parameters being performed. This is significant, as it is important to have the right combination of parameters at the right locations. Therefore, upgrading existing stations, for example, by installing ICOS-conform equipment and improving the measurement accuracy and precision e.g. by establishing quality control measures, have been used as ways to improve the network density and coverage.

Numerical growth information of the station types and the development of the network can be seen on the figure 10 on left.

Figure 10: Number of stations in 2015–2018



The total number of the stations was 131 at the end of 2017. In spring 2018, the number grew to 134 with Denmark bringing three new stations to the infrastructure.

GERMANY

We organised a celebration event at the Meteorological Observatory Hohenpeißenberg in December 2016, where Federal Minister Alexander Dobrindt symbolically started the operational phase of ICOS-D by clicking the "remote start" button of the newly established atmospheric station Gartow. The tower reaches a height of 340 m and is located near Dannenberg at the River Elbe in Northern Germany.

FRANCE

The French Ecosystem network was inaugurated in September 2015, a few weeks before the Paris Climate Agreement conference. The scientific colloquium gathered 80 participants and included invited lectures given by international experts covering key issues concerning the greenhouse gas balance of terrestrial ecosystems. It was attended by representatives of related French ministries and the president of the Region Nouvelle Aquitaine, M. Alain Rousset. The event received a large national press and media coverage.

THE NETHERLANDS

In Spring 2017, the ICOS-NL team requested funding from the national science agency, in collaboration with another research infrastructure, ACTRIS. The proposal "Ruisdael" asks for 10 years of support for our national activities in atmospheric science, including the contributions to ICOS-RI and ACTRIS. The proposal was successfully reviewed, and orally defended in front of a broad science committee in February 2018. The Ruisdael Observatory was approved later in Spring 2018. This will result in an update of the whole ICOS NL infrastructure, complete with secure funding for the next 10 years.

FINLAND

One of the first Ecosystem stations having been labelled was Siikaneva in Finland. The measurements at this ecosystem station include carbon dioxide and methane fluxes between the ecosystem and the atmosphere. The station also conducts meteorological measurements, such as air temperature and precipitation.

"The active standardisation work at Siikaneva started about 3 years ago. These three years have been an intensive time: four teams have worked hard to procure suitable equipment and to prepare it for the high ICOS standards. Last summer we literally crouched on the ground to document, for example, the vegetation and its growth in the area," says the head of the Siikaneva Ecosystem Station Eeva-Stiina Tuittila, Professor of Forest Soil Science at the University of Eastern Finland.

SWEDEN

The Swedish ICOS branch decided to build new two stations; Hyltemossa to the south of Sweden, near Lund; and Svartberget to the middle, close to Umeå. Now Sweden has a chain of stations covering Northern, Middle and Southern forest types in Sweden. The Hyltemossa and Svartberget are combined ecosystem and atmospheric stations, and have been operational since 2014, with both having a 150m tall towers, instrument buildings and working spaces for personnel. The Hyltemossa and Svartberget locations were selected because the surrounding areas are covered by forest areas typical for Southern and Middle Sweden, respectively. Both also fulfil our requirements in terms of flux footprint, topography and vegetation.

8 ICOS Impacts

ICOS has multiple impact. More accurate greenhouse gas information enables better science, provides important background information for decisions and helps avoid costly mistakes.

Measuring the impact of ICOS is challenging, since the benefits are spreading across society, decisions are based on many influences with science being only one of them, and results can only be seen at long timescales. To get a better grasp of its impact, ICOS has carried out a specific impact analysis with an external consultancy (Technopolis Group). The analysis maps different impact pathways and provides ICOS with Key Performance Indicators (KPIs) as well as methods to measure them. The analysis finished in June 2018.

SCIENCE IMPACTS

Although most of the stations were not yet labelled at the end of the reporting period, most of them have produced data for years already. Since 2014 this data has been available at the Carbon Portal. At the end of 2017, Carbon Portal hosted 3900 ICOS data objects, and more than 10 000 data objects overall. In April 2018, the Carbon Portal had 184 registered users. The total number of downloads was 8840 from all over the globe. This is impressive given that no higher level official ICOS data products were yet available.

ICOS data in other scientific databases and systems

Tracking the use of the pre-ICOS data in scientific products and publications has been a major challenge of the current impact analysis. ICOS' impact in scientific production is strongly underestimated by the lack of clear and correct attribution. The ICOS data citation system will be a major improvement to the current situation. Nevertheless, a significant impact can already be shown by large global data products containing pre-ICOS data. ICOS atmosphere stations contribute their time series to Globalview ObsPack products that are produced by NOAA Earth System Research Laboratory together with ICOS Carbon Portal. NOAA is the US National Oceanic and Atmospheric Administration. Since 2015, mainly scientific users have downloaded the ObsPack products (that carry a DOI) 680 times, for either inverse modelling studies or comparison between models and observations.

European ecosystem eddy covariance flux observations are thus far published for most of the existing ICOS stations through the FLUXNET database, which gathers ecosystem flux data globally. This database keeps track of all downloads and the use is indicated by the downloader. There are 49 European stations that contributed data to FLUXNET in the period 2005–2018.

Since the most recent FLUXNET release in 2015, the average number of downloads per site is above 900. Pre-ICOS data, all in all 317 datasets, from the ICOS marine stations were integrated into the past three versions of the Surface Ocean CO_2 Atlas (SOCAT) project, and to the Global Carbon Budgets 2015, 2016 and 2017.

Additionally, ICOS OTC data management staff supported the past versions of SOCAT and assembled the marine data used by the Global Carbon Budgets.

ICOS related scientific references and citations

Over 525 peer-reviewed scientific publications related to ICOS stations or pre-ICOS data have been reported since 2009, with a clear upward trend. This estimate is based on reporting by the national networks and central facilities and most certainly is an underestimation of the actual scientific production that is based on ICOS data. As can be seen in the figure 11, there was a substantial increase of reported publications in 2017.

Even more important than the number of publications is the number of citations of these. The figure above shows the large increase in the period 2013–2017. This underlines the high importance, timeliness, and relevance of the ICOS data and its science products.

Figure 11: ICOS related publications 2011–2018

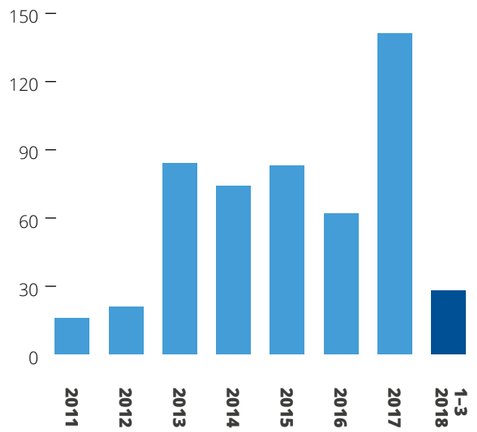
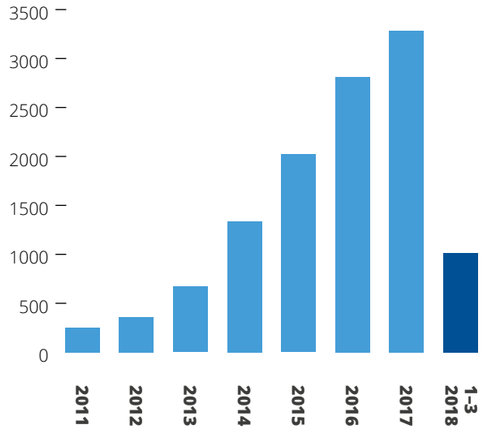


Figure 12: Citations of ICOS related publications 2011–2018



The publication and citation trends of ICOS data go strongly upwards, showing the increasing use of ICOS data in science.

Other scientific products with high impact

For the moment, perhaps the most significant effort in terms of scientific excellence is the production of the Atmosphere and Ecosystem station protocols, specifications, and instructions on measurement methodology, which assure the comparability of the measurements throughout the network. In the Ocean domain the necessary protocols were already existing, but for the Atmosphere and especially for the Ecosystem domain, these were created from scratch through joint efforts by the scientific community. In Ecosystem community, over 150 scientists participated in creating the protocols. These protocols are possibly becoming the international standard.

In 2017, ICOS Carbon Portal published and minted DOIs for the methane observation and modelling results of FP7 project "Integrated non-CO_2 Greenhouse Gas Observing System" (InGOS). A similar service was provided for the Global Carbon Project 2017. Publication of the latter resulted in a significant spike in the number of visits to Carbon Portal and has contributed to a steady increase in number of the visitors since then.

ICOS' role as a blueprint for other (global) initiatives that measure GHG was confirmed by the WMO and non-EU researchers who were interviewed in connection with the ICOS Impact Analysis in spring 2018. The role is also confirmed by various invitations to present ICOS standards in conferences or workshops.

For example, ICOS Ecosystem Thematic Centre, ETC, was invited to give a key note speech on standardization in a seminar on international collaboration organised by the Royal Flemish Academy of Belgium for Science and the Art. Ingeborg Levin of ICOS CAL was invited to the Heidelberg Physics faculty colloquium to present results from its 14C02 monitoring and its role as Central Radiocarbon Laboratory in ICOS RI. ICOS Director General Werner Kutsch presented the ICOS approach at several occasions to ESFRI, European Commission and national stakeholders. Additionally, many facets of ICOS have been presented constantly at European Geosciences Union General Assembly (EGU, annually in April) and American Geosciences Union Fall Meeting (AGU, annually in December).

CZECH REPUBLIC: ICOS SCIENTIST ACTIVE IN UN IPBES

Prof. Pavel Kindlmann from ICOS Czech Republic / CzechGlobe, is also active in the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). It is an independent intergovernmental body, providing policy-makers with objective scientific assessments about Earth's biodiversity, ecosystems and the benefits they provide to people, as well as the tools and methods to protect and sustainably use these vital natural assets. Prof. Kindlmann is responsible for coordinating the UN IPBES chapter report. In this work, he uses outcomes of ICOS.

CZECH REPUBLIC: ICOS HELPING TO ESTABLISH RESEARCH SITES IN TROPICAL COUNTRIES

ICOS Czech Republic has started a long-term collaboration project with scientific and governmental partners from Panama, Vietnam and Ghana, which is focusing on establishing a carbon cycles research and monitoring site in these tropical countries. With carbon dioxide observations in these countries, the global greenhouse gas balances can be better observed and modelled.

Scientific community building

ICOS ERIC actively and effectively constructs knowledge and innovation communities. One remarkable achievement of ICOS has been in uniting European research communities from different scientific domains – the atmosphere, oceans, and different ecosystems. This is globally unique and makes ICOS a highly appreciated partner in global earth observation networks as well as within the network of research infrastructures. It also has strengthened the national networks of greenhouse gas scientists through the establishment of their own national ICOS consortia.

A core activity to bring the scientific community together, is the bi-annual ICOS Science Conference, the first being held in Brussels in September 2014 and the second in Helsinki in September 2016. The conferences fostered the internal integration of ICOS, as they were attended by more than 200 and 250 participants, respectively, who presented more than 50 lectures and over 100 poster presentations. Furthermore over 10 000 Twitter users were reached by the Science Conference in 2016.

ICOS is stepwise also becoming a core player in the connection between remote sensing and in-situ observation. Connections between ICOS, Copernicus and ESA, the European Space Administration are expected to rise to the level of formal collaboration in the future.

"One can thus conclude that ICOS ERIC succeeds in creating a GHG-measurement community in Europe that spans domains, generates new ideas and starts to become self-propelling. Some evidence has been found that indicates towards ICOS' shaping of European (national) research agendas." (ICOS Impact Analysis, Mid-Term Report, April 2018)

Beyond its core field of GHG observations, ICOS ERIC is a key player in building a cooperative community of European environmental research infrastructures. These organisations co-operate within the ENVRIplus cluster project, co-ordinated by ICOS. The mid-term report of the ENVRIplus project in 2017 stated: "This is a highly impressive project. It is extremely well run, and its level of achievement relative to its budget is very high. The resources are used wisely and represent excellent value for money. ENVRIplus has achieved a huge amount of very good work, across highly complex, multi-layered areas, with excellent outputs and outcomes already." ENVRIplus project is presented in more detail in chapter 9.

Additionally, ICOS ERIC maintains a communications network for the RI communication officers from the Environmental RIs. The aim is to share the knowl-

edge and best practices, and at the same time, promote the project's results within the RIs themselves. Similarly, ICOS initiated a communications network for other RI clusters (CORBEL, EMBRIC, PARENTHOS, ASTERICS, SINE2020) in 2017, to regularly share the best practices in promoting the cluster projects and to improve the exploitation of results. In addition to the virtual meetings, the group has set up a joint virtual space to improve collaboration and sharing of information.

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 indicate that the high ICOS standards drive them to increase their product quality. Especially testing and calibration conducted at the ICOS sites, and the organisation of meetings and events were mentioned.

Examples of co-operation between the industry and ICOS are both with the Atmosphere and the Ecosystem Thematic Centres. The ATC metrology lab has built collaboration with industrial companies to test emerging technologies. Innovative ICOS ATC software is used by ICOS PIs for quality control and for station network management system. The ETC and Carbon Portal needed a specific logger for the automatic data submission process. "I interacted a lot with different companies in the field at the time of developing the process. Now some companies develop their products according to ICOS standards. It benefits both parties, as we get to purchase good quality products, and the companies can say they fulfil the tight ICOS standards," says Dario Papale, Director for the Ecosystem Thematic Centre. The industrial partners expect that the influence from ICOS on their market will increase when ICOS starts to publish data based on their products (ICOS Impact Analysis, Mid-Term Report, 2018).

SOCIO-ECONOMIC IMPACT

There is no question that ICOS has socio-economic impact, however, there are many questions on how to describe it. The 'Group of Eight' leading universities in Australia have listed the types of impacts in a background paper: impact of research can be indirect, long-term, depending on forces outside the research system, and even negative. Environmental research infrastructures in general, and ICOS in particular, generate important knowledge on our ecological life support systems that provide priceless services. This is especially evident in the field of greenhouse gas management: if we do not reach our safe climate change target level due to inadequate mitigation, the climate change will lead to extremely large societal costs caused by adaptation efforts, losses and damages. Compared to the values at risk, the investments and running costs needed for a global greenhouse gas monitoring and analysis network are marginal and would easily provide return due to improved effectiveness of the science-guided mitigation strategies.

Direct economic impact

ICOS has been built on investments of about EUR 80 million in the participating countries. The funding has been used mainly in scientific instrumentation and for labour to design and implement the infrastructure. Overall, ICOS has unlocked more than EUR 20 million of additional funding from the European Commission. The capital value has been estimated to be above EUR 100 million since developing ICOS was also supported by in-kind and external resources; e.g. from host institutions, national ministries, the ESFRI and the European Commission. ICOS has increased the continuity of measurement sites, and with that, the return of earlier investments. New sites can be erected in a much more efficient way due to standardisation that also benefits researchers outside ICOS and outside Europe. The fringe event 'Observing the Anthropocene – Global in-

ICOS SWITZERLAND: A VIRTUAL REALITY TOUR AT ECOSYSTEM STATION

A virtual reality tour was created for the ecosystem site Davos and was shown during various outreach activities: Scientifica Zürcher Wissenschaftstage, science fair for the Zurich public, ETH Science City, and ETH unterwegs in 2017

ICOS BELGIUM: OPEN HOUSE AT STATION AND SCHOOL EDUCATION MATERIAL

In November 2017, ICOS Belgium organized an open house at the Brasschaat ecosystem station. The event consisted of guided tours around the station and the forest, and climate change experiment workshops for children. Over 120 visitors of all ages participated. Before the actual event, its concept was tested with two school classes with altogether some 40 students aged 12–15 visiting the station. The aim is to develop the workshop on climate change and ICOS into a travelling concept, which will visit schools. The first trial was on May 2018.

BELGIUM: ICOS MENTIONED AS AN EXAMPLE OF COLLABORATION IN MINISTERIAL COMMUNICATION

Federal Minister of Science Zuhal Demir, mentioned ICOS in a Policy Note in 2017 as an example of international collaboration and of specialised research infrastructures. In the same note the investment into a new research vessel that will replace RV Belgica – Belgian's third ocean observation station – was also mentioned.

ICOS CZECH REPUBLIC: ICOS DIRECTOR RECEIVED A CITY AWARD

One indicator of the impact and importance of the ICOS national networks is the Brno City Award that the director of RI CzeCOS, professor Michal V. Marek was awarded in 2017 (Cena města Brna 2017). The grounds for this award were the results of the climate change research, and among others, the establishment and successful operation of RI CzeCOS.

frastructure cooperation on environmental challenges' co-organised by ICOS at the International Conference on Research Infrastructures in 2016 perhaps serve as a good example of that.

Society and political influence

ICOS' task at the political level can be best described as the contribution of timely information relevant to the greenhouse gas policy and decision-making; supporting efforts towards a fulfilment of the resolutions of the Paris climate conference aimed at mitigating climate change. However, greenhouse gas measurements and respective reports, influence decisions only indirectly.

Covering the whole range of essential climate variables needs cooperation between different research infrastructures and organisations. Additionally, close collaboration is needed with the societal end-users of these observations to base climate policy and decisions on best available science, as required by the Paris Agreement.

To better define its international position within the landscape of intergovernmental organisations, ICOS has actively participated in the United Nations Framework Convention on Climate Change (UNFCCC) Conferences of Parties, COP21 in Paris, COP22 Marrakesh, and COP23 in Bonn, both in the official program and in side events.

The UNFCCC has a well-established system for global climate observations (Integrated Global Greenhouse Gas Information System, IG3IS, in which the commonly agreed essential climate variables are defined by Global Climate Observing System (GCOS). Greenhouse gas observations are an essential component of this system and ICOS is a key European contributor to these observations. In the interviews conducted by the ICOS Impact Analysis, WMO officials mention that the ICOS data and measurement standards are the best available in the world and that ICOS data is the core for global data inventories.

Not surprisingly, contacts with the WMO are very active and high-level, e.g. by ICOS Director General and WMO Secretary-General. Additionally, ICOS Carbon Portal Director chairs the scientific advisory board for greenhouse gases for the WMO Global Atmosphere Watch program (GAW) and has presented also ICOS data processing and data portal concepts within this framework. Many ICOS scientists, for example from the Head Office, Carbon Portal, and Atmospheric Thematic Centre, participated in an Inversion workshop organised by the EU Joint Research Council in June 2017.

Additionally, ICOS Carbon Portal Director is a member in the executive steering group of the afore mentioned Integrated Global Greenhouse Gas Information System (IG3IS) initiated by WMO. The IG3IS uses emissions 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's also noteworthy that several ICOS PIs act as lead authors in writing the IG3IS implementation plan.

Since 2016 ICOS has been a Participating Organization in Group on Earth Observations (GEO) which is a network of over 100 member countries and 120 participating organisations. It 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, and to increase the use of ICOS data and data products as well as to co-design the services expected from ICOS.

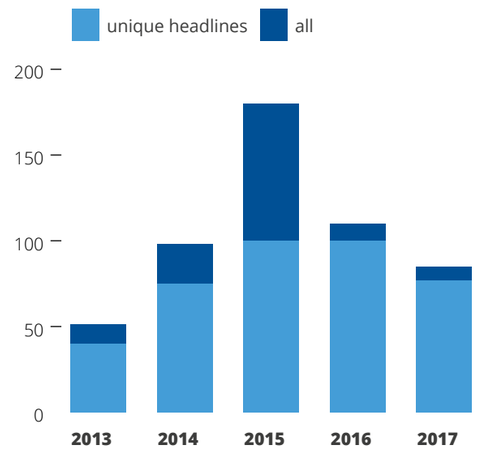
Furthermore, ICOS co-initiated a GEO Carbon and Greenhouse Gas Initiative (GEO-C) in 2016 and was elected to host its secretariat in 2017. The GEO-C serves as an informal discussion forum between the major actors in the UNFCCC framework: IPCC, UNFCCC, the European Commission, WMO, Copernicus, satellite observations via Committee on Earth Observation Satellites (CEOS), and in-situ component covered by ICOS. One of the short-term goals of GEO-C is to map the organisations and their contributions to requirements by the UNFCCC and how these can support national climate change mitigation. This leads to a roadmap of how scientific actors can best support the implementation of the Paris Agreement. In connection with the GEO-C secretariat, ICOS also participated in, or co-convened several events, side-events and sessions during 2016 and 2017.

Several ICOS units provide their expertise for the Copernicus in-situ coordination project lead by European Environment Agency. ICOS is represented by Carbon Portal, and Atmosphere Thematic Centre and Central Radiocarbon Laboratory provide their expertise e.g. on $^{14}CO_2$ observations for fossil fuel CO_2 estimates. ATC participates in Copernicus Atmosphere Monitoring Service (CAMS) project which aims to consolidate and improve

the preparation, transmission and quality control of Near Real Time atmospheric ICOS data for the usage of and other users (CAMS26). The data in the Copernicus service will be used, for example, by national weather services or private companies to improve air pollution predictions, but also to develop other data products using ICOS data, such as maps of fossil fuel emissions.

Finally, ICOS has a unifying effect on the governmental levels by means of science diplomacy. An international collaboration like ICOS brings together not only scientists but also representatives of science and environment-related ministries that participate. Persons external to ICOS member countries, who were interviewed to the Impact Analysis, do mention the fact that states from the EU 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 non-trivial.

Figure 13: The number of media articles mentioning ICOS in the period of 2013–2017.



Increasing Awareness

The most important external communications channel for ICOS was social media: Twitter, Instagram, YouTube and LinkedIn were used the most.

In July 2017, ICOS decided to use social media more efficiently to gain visibility for greenhouse gas measurements and climate change within the general audience. For that purpose, a social media campaign ICOScapes visits 12 stations – one in each country. The campaign publishes beautiful station photos and videos including station crew interviews on social media. For still photos, a professional, well-known nature photographer was enlisted. In 2017, three of 12 ICOS countries were covered: Italy, Denmark, and Norway. The campaign has been very successful. In addition to multiplying the ICOS social media coverage, it has also connected the audience to ICOS, which is shown by the likes and positive comments received. Videos were also shown e.g. in the ICOS Nordic Symposium, GEO Week 2017, COP23 and at EGU 2018, where they received positive comments. Furthermore, on the photographer Konsta Punkka's Instagram account, #ICOScapes photos have gained between 35 500 to 91 000 likes each, as well as positive comments.

All in all, ICOS' presence in all social media channels has grown much stronger during 2017, mainly thanks to the ICOScapes campaign. In addition to ICOS RI, there are at least 14 other ICOS accounts on Twitter: Carbon Portal, some national networks, some single stations etc. At the end of 2017, the RI Twitter accounts had approx. 2950 followers in total.

In terms of other web presence, the visibility has been relatively stable or shown moderate growth. In addition to ICOS RI and Carbon Portal websites, which were established at 2015, there are at least 12 other ICOS related websites: Each of the Thematic Centres and almost all the National Networks have their respective websites. All units did not count their visitors; for those who did, the average number was 2500 unique visitors per month in Aug–Dec 2017.

The number of general media articles concerning ICOS RI has been around 90–100 articles, (with unique headlines) in a year, from 2015 through 2017. The media attention was highest in Finland, the United States and Germany, however, all participating countries had some news coverage.

9 Externally funded projects

ICOS ERIC coordinates or participates in several projects funded through the European Commission Horizon 2020 Work Programme. All the projects greatly contribute to the development of ICOS RI through the step-up developments made within these projects. The most significant EU projects for ICOS are shortly described in the following chapters.

RINGO – READINESS OF ICOS FOR NECESSITIES OF INTEGRATED GLOBAL OBSERVATIONS

ICOS ERIC has been coordinating RINGO since January 2017. RINGO aims to further develop and foster sustainability and readiness of ICOS via scientific, technical and managerial developments, and by deepening ICOS' integration into global observation and data systems. RINGO activities will thus directly contribute to most of the tasks as they are outlined in the ICOS Statutes.

RINGO initiated the work on ICOS impact analysis and geographical expansion. The Impact Analysis will produce an ICOS user strategy document that recognizes the different user groups, types of data that is used and how the data is accessible. The results of the study will be available during 2018. ICOS geographical coverage, in turn, is enhanced through engagement of the new countries and development of the network, mostly by facilitating joint workshops and meetings with relevant non-ICOS country scientists.

ENVRIPLUS – ENVIRONMENTAL RESEARCH INFRASTRUCTURES PROVIDING SHARED SOLUTIONS FOR SCIENCE AND SOCIETY

ICOS ERIC actively cooperates with other European environmental research infrastructures both bilaterally and, since 2015, also within the framework of the ENVRIplus project. Since January 2017, ICOS ERIC acts as official Coordinator. This project focuses on integration, interoperability and harmonization of the European Environmental Research Infrastructures (Env RI), which is of strategic importance for ICOS. The ENVRIplus programme positions ICOS on the frontline amongst the other ESFRI projects, landmarks and integrated activities, and offers ICOS greater visibility inside and outside of the Env RI community. The main benefits are achieved when ICOS and other RIs are developed in a consistent, common and cost-effective way.

Concrete outcomes include a study on the further integration of research infrastructures related to terrestrial ecosystem research including recommendations on co-locating research sites on the national and international level. ICOS observation network can greatly benefit from this plan on domain integration in the future; such a study enhanced the position of ICOS amongst the other ecosystem RIs.

Further, analysis of the ICOS interoperability requirements was conducted, and this allowed comparison and discussion leading to best practice and consistent development plans for ICOS improvement and also RI interoperation; this activity helped standardisation and improvement of ICOS data life cycle.

ENVRIplus also helped to facilitate the cooperation between ICOS and key international data-oriented initiatives, impacting the development of global environmental open data systems as well as other initiatives.

SEACRIFOG – SUPPORTING EU–AFRICAN COOPERATION ON RESEARCH INFRASTRUCTURES FOR FOOD SECURITY AND GREENHOUSE GAS OBSERVATIONS

ICOS ERIC is a major partner of the EU Horizon 2020 SEACRIFOG project. It focuses on the design of a pan-African observational system on GHG and aerosols observations and measurements, with a special emphasis on land-use, land-use change and climate-smart agriculture. SEACRIFOG brings together data providers, users of the data, and possible funders.

During 2017, the existing capabilities, greenhouse gas observational networks, and main agricultural systems have been identified. The second phase that started in spring 2018, will design a possible greenhouse gas measurement network to contribute to fill the gap of scientific data over the African continent. This will increase the accuracy of the existing climate models and reinforce the cooperation between African infrastructures and their European counterparts. This is in alignment with several articles in the ICOS statutes.

In the SEACRIFOG project, ICOS has also set up a high-level dialog platform gathering African and European major stakeholders who will contribute to the implementation and the sustainability of the observational network proposed in the project.

RISCAPE

ICOS ERIC is a partner in a RISCAPE project, which started in 2017. The project provides an analysis of the international landscape of research infrastructures in eight different domains. ICOS is in charge of the work package dedicated to environmental sciences. With the survey of the major infrastructures and initiatives outside of Europe, ICOS will be able to establish a map of technical, geographical and scientific complementarities within the European landscape of RIs. This will be critical when ICOS engages in new international co-operation opportunities.

EUDAT2020

ICOS Carbon Portal participated in EUDAT H2020 project that ran from March 2015 until Feb 2018. It brought together a unique consortium of e-infrastructure providers, research infrastructure operators, and researchers from a wide range of scientific disciplines under several of the ESFRI themes, working together to address the new data challenge.

The project explored new approaches to data management and data preservation, access and sharing support, aiming to enable scientists to preserve, find, access, and process data in a trusted environment, as part of a Collaborative Data Infrastructure (CDI). The CDI supports the whole life-cycle of scientific research data.

One of the main ambitions of EUDAT2020 was to bridge the gap between research infrastructures and e-Infrastructures through an active engagement strategy. During its three-year funded life, EUDAT2020 evolved the CDI into a healthy and vibrant data-infrastructure for Europe, and positioned EUDAT as a sustainable infrastructure within the future European Open Science Cloud.

Appendix: Governing persons

HO AND CF DIRECTORS 2015–2017

2015–2017
Werner Kutsch, Director General
Alex Vermeulen, Carbon Portal Director
Ingeborg Levin, Central Radiocarbon Laboratory Director
Armin Jordan, Flask and Calibration Laboratory Director
Leonard Rivier, Atmosphere Thematic Centre Director
Dario Papale, Ecosystem Thematic Centre Director
Truls Johannessen, Ocean Thematic Centre Director

ICOS GENERAL ASSEMBLY 2015–2017

Chair of General Assembly
Jean-Marie Flaud, FRANCE (2016–)

Vice-Chair of General Assembly
Petteri Kauppinen, FINLAND (2017–)

Delegates
Bruno Blanke, FRANCE (2016)
Antonio Bombelli, ITALY (2015–)
Jon Børre Ørbaek, NORWAY (2015–)
Thierry Caquet, FRANCE (June 2017–)
Hana Dlouhá, CZECH REPUBLIC (2016–)
Jiri Dusek, CZECH REPUBLIC (2016–)
Dirk Engelbart, GERMANY (2015–2016)
Paul Filliger, SWITZERLAND (2015–2016)
Didier Flagothier, BELGIUM (2015–)
Magnus Friberg, SWEDEN (2015–)
Thomas Friborg, DENMARK (2016–)
Helene Frigstad, NORWAY (2016)
Kaarle Hämeri, FINLAND (2015–2017)
Marc de Jonge, NETHERLANDS (2015–)
Petteri Kauppinen, FINLAND (2015–)
Jiri Kolman, CZECH REPUBLIC (2016–)
Salvatore La Rosa, ITALY (2015–)
Magnus Lund, DENMARK (2016–)
Helene Lundqvist, SWEDEN (2015–2016)
Valérie Moulin, FRANCE (2015–)
Michèle Oleo, BELGIUM (2015–)
Gelsomina Pappalardo ITALY (2015–)
Kim Pilegaard, DENMARK (2016–)
Christian Plass-Duelmer, GERMANY (2017–)
Troels Rasmussen, DENMARK (2016)
Patricia Roussel-Chomaz, FRANCE (2015–)
Regine Röthlisberger, SWITZERLAND (2017–)
Richard Sanders, THE UNITED KINGDOM (2016–)
Sanna Sorvari, FINLAND (2015–)
Jean-François Soussana, FRANCE (2016–June 2017)
Johanna Spångberg, SWEDEN (2017–)
Martine Vanderstraeten, BELGIUM (2015)
Stine Van Bovtrup, DENMARK (2016–)
Aline Van der Werf, BELGIUM (2015–2016)
Petr Ventluka, CZECH REPUBLIC (2016–)
Bernard Westerop, NETHERLANDS (2015–)

Appendix: Contacts, ICOS ERIC

ICOS Research Infrastructure: **www.icos-ri.eu**
ICOS Carbon Portal: **www.icos-cp.eu**

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linkedin.com/company/icos---integrated-carbon-observation-system

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The Progress Report 2015–2017 has been on the agenda of the 6th ICOS ERIC General Assembly, held in May 31, 2018.

ICOS/GA06/2018/4

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Appendix: List of Partners

71 partners were involved in the ICOS RI in 2016–2017.

These included funding and science performing institutions and universities, and other representing entities. The partners are listed below by country.

BELGIUM
Royal Belgian Institute for Space Aeronomy

Royal Belgian Institute of Natural Sciences

Belgian Science Policy Office (BELSPO)

Department of Economy, Science and Innovation (EWI), Flemish Government

Service public de Wallonie (SPW)

Research Foundation – Flanders

University of Antwerp

The Research Institute for Nature and Forest

University of Hasselt

Flanders Marine Institute

University of Liege

CZECH REPUBLIC
Ministry of Education, Youth and Sports

Global Change Research Institute of the Czech Academy of Sciences

DENMARK
Ministry of Higher Education and Science

Danish Agency of Science, Technology and Innovation

University of Copenhagen

Aarhus University

Roskilde University

Technical University of Denmark

FINLAND
Ministry of Education and Culture

Ministry of Transportation and Communications

Finnish Meteorological Institute (FMI)

University of Helsinki (UHEL)

University of Eastern Finland

FRANCE
Ministry of Higher Education, Research and Innovation – Direction générale de la Recherche et de l'Innovation

The National Centre for Scientific Research (CNRS; INSU and INEE)

French Alternative Energies and Atomic Energy Commission (CEA)

French National Institute for Agricultural Research (INRA)

University of Versailles-Saint-Quentin-en-Yvelines (UVSQ)

French National Radioactive Waste Management Agency (ANDRA)

French Space Agency (CNES)

French Research Institute for Development (IRD)

French Meteorological Institute – Météo-France

French National Museum of Natural History

French Geological Survey (BRGM)

French Polar Institute (IPEV)

Agro-ParisTech – Paris Institute of Technology for Life, Food and Environmental Sciences

Aix-Marseille University

University of Avignon

Bordeaux-Sciences-Agro

University of Clermont-Ferrand

University of French West Indies and Guiana

Université Grenoble Alpes

University of Lorraine

University of Montpellier

Montpellier SupAgro, International Center for Higher Education in Agricultural Sciences

University of Orléans

Université Paris-Saclay

Université Paul Sabatier, Toulouse

Paul Valéry University of Montpellier III

University of Reims Champagne-Ardenne

Sorbonne University, Paris

University of Réunion Island

Unversity of La Paz, Bolivia

University of Abidjan (Côte d'Ivoire)

Unversity of Crete, Heraklion (Greece)

National University of Ireland, Galway (Ireland)

GERMANY
Federal Ministry of Transport and Digital Infrastructure (BMVI)

Federal Ministry of Education and Research (BMBF)

Heidelberg University

Max-Planck-Institute for Biogeochemistry (MPI)

GEOMAR Helmholtz Centre for Ocean Research

Thünen Institute

German Weather Services Deutscher Wetterdienst (DWD)

Karlsruhe Institute of Technology (KIT)

Jülich Researsch Centre (FZJ)

Helmholtz Centre for Environmental Research, Leipzig (UFZ)

Dresden University of Technology

Georg-August-University Göttingen

Weihenstephan-Triesdorf University of Applied Sciences

Alfred Wegener Institute (AWI)

The Leibniz Institute for Baltic Sea Research (IOW)

ITALY
Ministry of Education, Universities and Research, Department for the universities, higher education establishments in art, music and dance

Italian Research Council (CNR), Dipartimento Scienze del Sistema Terra e Tecnologie per l'Ambiente

Euro-Mediterranean Center on Climate Change (CMCC)

University of Tuscia (UNITUS)

ICOS Italy Joint Research Unit

Council for agricultural research and the analysis of the agrarian economy (CREA)

Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)

Agenzia regionale protezione ambiente (ARPA)

The University of Udine

The Edmund Mach Foundation

Universita Cattolica

Free University of Bozen-Bolzano

The University of Sassari

The University of Padova

The University of Genoa

National Institute of Oceanography and Applied Geophysics

South Tyrolean State Administration

THE NETHERLANDS
Ministry of Education, Culture and Science

Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NOW)

University of Wageningen (WUR)

University Amsterdam

University of Groningen

Energy research Centre of the Netherlands (ECN)

Wageningen Environmental Research (Alterra)

Utrecht University

Royal Netherlands Meteorological Institute (KNMI)

SRON Netherlands Institute for Space Research

Royal Netherlands Institute of Sea Research (NIOZ) and TNO Research

NORWAY
Royal Norwegian Ministry of Climate and Environment, Department for Nature Management

The Research Council of Norway

Bjerknes Centre of Climate Research (BCCR)

University of Bergen

Uni Research

Norwegian Institute for Agricultural and Environmental Research (NBIO)

Norwegian Institute for Air Research (NILU)

Norwegian Polar Institute

Norwegian Institute of Bioeconomy Research

Centre for International Climate and Environmental Research (CICERO)

Institute for Marine Research (IMR)

SWEDEN
Swedish Research Council

University of Lund (LU)

University of Gothenburg

Stockholm University

Swedish Polar Research Secretariat

Swedish University of Agricultural Sciences

Uppsala University

SWITZERLAND
Federal Department of Economic Affairs, Education and Research (EAER), State Secretariat for Education, Research and Innovation (SERI)

Federal Department of the Environment, Transport, Energy and Communications (DETEC), Federal Office for the Environment (FOEN)

ETH Zurich, Institute of Agricultural Sciences

University of Bern

EMPA Material Science and Technology

Swiss Federal Institute for Forest, Snow and Landscape Research (WSL)

University of Basel

Schweizerische Eidgenossenschaft

Federal Department of Home Affairs

MeteoSwiss

UNITED KINGDOM
National Oceanography Centre Southampton (NOC), University of Exeter

Plymouth Marine Laboratory (PML)

MET Office

Plymouth Marine Laboratory

Centre for Ecology and Hydrology

National Centre for Atmospheric Science

University of East Anglia

University of Exeter

ICOS – Integrated Carbon Observation System

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