TECHNICAL AND SCIENTIFIC DESCRIPTION OF ICOS RESEARCH INFRASTRUCTURE (ICOS RI)

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1. Vision and Mission

1.1 Background

Climate change is one of the most challenging problems that humanity will have to cope with in the coming decades. The Intergovernmental Panel on Climate Change (IPCC) has concluded that a large part of the observed rise of global temperature is very likely due to increasing greenhouse gases in the atmosphere, driven by man-made emissions overtaking the natural cycles of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The perturbed global biogeochemical cycles of these greenhouse gases are a major driving force of current and future climate change.

These changes are caused by human activities; the primary agents of change are fossil fuel combustion and modifications of global vegetation through land use change, in particular deforestation. The natural carbon cycle offers a discount of ca. 50% by absorbing about half of the anthropogenic emissions. It is not clear, however, if these CO_2 sinks will operate in the future under a changing climate and increasing human impacts. At the current atmospheric trace gas composition, the natural oxidizing power of the atmosphere cleans up almost all the CH_4 injected by human and natural sources but expected increases of emissions will further raise CH_4 concentrations.

Deeper understanding of the driving forces of climate change requires full quantification of the greenhouse gas emissions and sinks and their evolution. Regional greenhouse gas flux patterns, tipping-points and vulnerabilities can be assessed by long term, high precision observations in the atmosphere and at the ocean and land surface. With decreasing model errors the availability and accuracy of observational data will emerge as the limiting factor, and even today calibration offsets between stations possibly bias flux estimates.

The United Nations Framework Convention on Climate Change (UNFCCC) requires from Parties to monitor Essential Climate Variables and the reporting under the Convention and Kyoto Protocol requires emission inventories. ICOS data can be used to verify those inventories.

1.2 Mission

The mission of the ICOS RI is to enable research to understand the greenhouse gas (GHG) budgets and perturbations. The ICOS RI provides the long-term observations required to understand the present state and predict future behavior of the global carbon cycle and GHG emissions. Technological developments and implementations, related to GHGs, will be promoted by the linking of research, education and innovation.

2. Objectives

The first objective of the ICOS RI is to provide effective access to a single and coherent data set to facilitate research into multi-scale analysis of GHG emissions, sinks and the processes that determine them. The ICOS RI aims to establish a template for the future development of similar integrated and operative GHG observation networks also beyond Europe.

The second objective is to provide information, which is profound for research and understanding of regional budgets of greenhouse gas sources and sinks, their human and natural drivers, and the controlling mechanisms. The ICOS RI will permit to detect changes in regional greenhouse gas fluxes, early warning of negative developments and the response of natural fluxes to extreme climate events, to reduce uncertainties in Earth System models and their predictions.

3. Unique values of the ICOS RI

The ICOS RI undertakes and coordinates a variety of Pan-European actions:

a) To quantify GHG atmospheric concentrations and terrestrial and oceanic fluxes over Europe and key regions of European interest, including the North Atlantic Ocean;
b) To facilitate European research programmes and projects;
c) To contribute to the mobility of knowledge and/or researchers within ERA and increase the use of intellectual potential throughout Europe;
d) To coordinate and support the development of technology and protocols for high-quality and cost efficient measurements of GHG concentrations and fluxes, also to be promoted beyond Europe;
e) To contribute with timely information to the GHG policy and decision making;
f) To facilitate analyses of the effectiveness of carbon sequestration and/or GHG emission reduction activities on global atmospheric composition levels, including the estimates of ground-level sources and sinks.

Even though the ICOS RI station network is designed to monitor managed and natural ecosystems and oceanic fluxes rather than anthropogenic emissions, the ICOS RI will provide independent data to help improving emission inventories using atmospheric chemistry and transport models, for monitoring the applications of international conventions like the Kyoto protocol.

4. Structure

The structure of the ICOS RI consists of the ICOS National Networks (ICOS NN), ICOS Central Facilities (CFs), operated either at national or at multi-national level, and ICOS ERIC. The components of the ICOS RI are able to form their own consortia to run their tasks in the ICOS RI. The ICOS Central Facilities include Atmospheric Thematic Centre (ATC), Ecosystem Thematic Centre (ETC), Ocean Thematic Centre (OTC) and Central Analytical Laboratories (CAL). The ICOS ERIC includes the Head Office (HO) and Carbon Portal (CP), which manage the activities of the ICOS RI.

The backbones of the ICOS RI are the ICOS National Networks consisting of atmospheric, ecosystem and marine stations. The ICOS atmospheric and ecosystem networks are planned to include more than 50 fully equipped Class-1 atmospheric and more than 50 Class-1 ecosystem stations located across Europe, supplemented by Class-2 stations with the same analytical precision but less physical parameters measured. The ICOS marine network covers the North Atlantic and European marginal seas. The marine observation system will consist of approximately 15 major instrumented “ships of opportunity” and 15 fixed time series stations. Precise concentration measurements are supported by the Central Analytical Laboratories (CAL). The data from the networks are collected and processed in the ATC, ETC and OTC and finally gathered in and made accessible via the Carbon Portal (CP). The Monitoring Station Assemblies (MSAs) for atmosphere, ecosystem and marine networks consist of scientific and technical experts from the stations of the ICOS National Networks of the ICOS ERIC Member countries. The MSAs monitor, develop and improve the scientific and technical basis (e.g. station networks) of the ICOS RI, and they work closely with the ICOS Central Facilities.

The organizational components of the ICOS RI are presented in Fig. 1. The ICOS ERIC legal entity is established to coordinate the operations of the ICOS RI, and to develop, monitor and integrate the activities of the ICOS RI. The statutory seat of ICOS ERIC is in Helsinki, Finland. The Head Office is operated by Finland together with France. ICOS ERIC includes governance bodies such as the General Assembly advised by a Scientific Advisory Board and an Ethical Advisory Board, and the Director General, supported by the ICOS Research Infrastructure Committee. ICOS ERIC shall have agreements with the ICOS National Networks and ICOS Central Facilities integrating them into the ICOS RI and its activities.

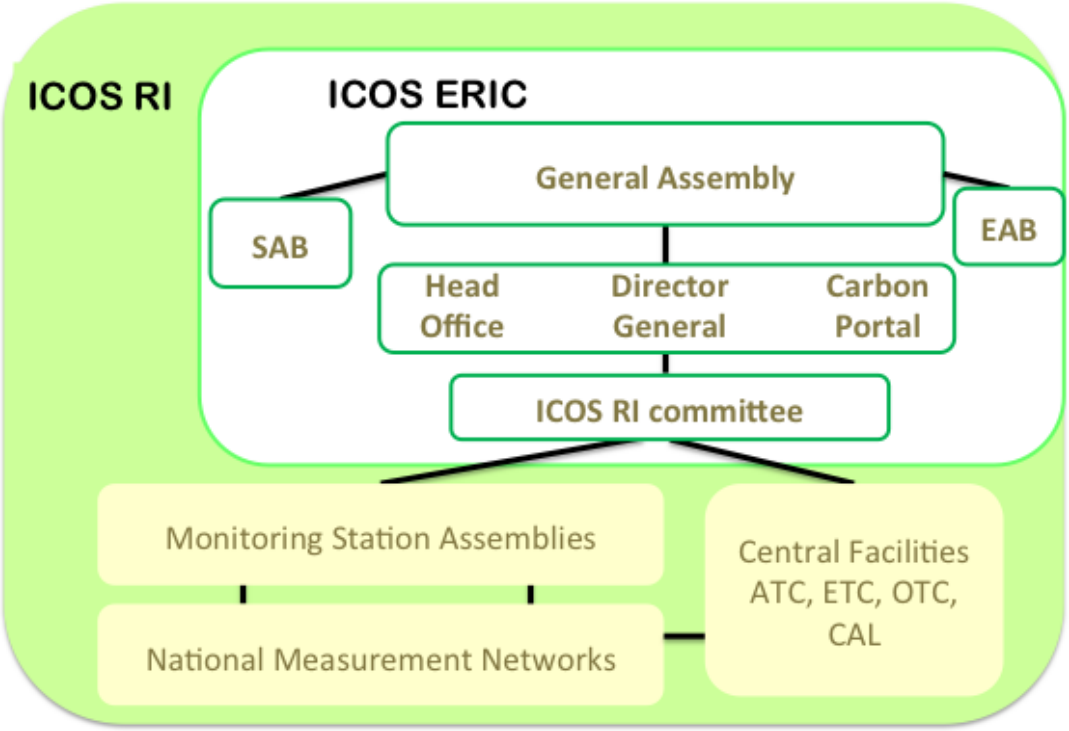

Fig. 1. Organisational structure of the ICOS RI. SAB is Scientific Advisory Board. EAB is Ethical Advisory Board, ATC, ETC and OTC are Atmospheric, Ecosystem and Ocean Thematic Centre, respectively. CAL is Central Analytical Laboratory.

All ICOS Central Facilities (CFs) outside the ICOS ERIC will make agreements with the ICOS ERIC to commit to the jointly agreed deliverables of the ICOS RI operations and to allow money transactions from the ICOS ERIC to the ICOS CFs. Appended to the contracts are lists of deliverables expected from the ICOS CFs as a part of the ICOS RI. The risk assessment is included in the implementation plan of the whole ICOS RI as well as in the implementation plans of HO, CP and CFs. The evaluation of the risk assessment is part of the regular ICOS RI evaluation every five years. Main risks are identified to be linked to the involvement of the hosting country, the staff number and their skills and the amount of funding. The ICOS ERIC will annually monitor the CFs on the basis of Key Performance Indicators (KPI) developed in the implementation plan. ICOS RI KPIs are defined following the guidelines of the European Commission to research infrastructures. The ICOS ERIC also takes note of the transparent budget reporting and indicative long term financial plans of the CFs. The contracts between the CFs and ICOS ERIC form the basis for continuous monitoring of the functioning of the CFs, and their co-funding through basic national funds and ICOS ERIC station contributions.

Agreements will also be made between the ICOS ERIC and the organisations/countries running the ICOS National Networks. This is to help the ICOS ERIC to manage and steer the network extension, and help the ICOS national networks to commit themselves to the station qualifications and data quality requirements (see below 5.1).

5. Activities

5.1 ICOS National Networks (of stations)

5.1.1 Atmospheric stations

Each ICOS Atmospheric Station (ICOS AS) is an observatory established to measure continuously the concentration variability of greenhouse gases (CO_2, CH_4) and other trace gases (e.g. CO) due to regional and global fluxes. A site chosen for installing an atmospheric station will be typically representative of a footprint area of more than 100 km^2. Additional stations, with a more local footprint, for instance located in areas of high local emissions, will be associated into the network. These associated stations will meet the same precision requirements as the main ICOS stations. The ICOS AS will be equipped with commercially available instruments associated into an "integrated" measurement system, controlled by a computer and custom-made software. ICOS AS's modular character will allow for different configurations. Two classes of stations exist: Class-1 ICOS AS: complete equipment for measuring the full set of ICOS AS core parameters and Class-2 ICOS AS: equipment for measuring a predefined subset of the ICOS AS core parameters.

The addition of novel instruments into the existing ICOS AS structure for measuring additional gas species (e.g. SF_6, etc.) or replacements of the existing instruments with more advanced ones at a later date may occur.

5.1.2 Ecosystem stations

The ICOS Ecosystem Stations (ICOS ES) are based on instrumentation, partly commercial, embedded into an integrated system for ecosystem monitoring. As the ecosystem monitoring involves human intervention on field activities (such as plant and soil sampling), the ICOS ES will follow a set of rigorously standardized protocols developed for the field ecosystem measurements.

The ecosystem network adheres to the monitoring principles of the Global Climate and Terrestrial Observing Systems (GCOS and GTOS). These consist of an established set of principles (GCOS Climate Monitoring Principles) that need special attention in their practical execution. They concern detailed measurement protocols, quality control and data management plans for secure long-term operation. The instrument setup and measurement protocols of the ICOS ES follow these guidelines ensuring that the instrumentation yields observations of comparable accuracy and that the changes in setups are documented and traceable.

The ecosystem network includes two classes of the ICOS ES, referred to as Class-1 (complete) and Class-2 (basic) stations, which differ in costs of construction, operation and maintenance due to a reduced number of variables

measured at the Class-2 stations. This strategy will enhance flexibility and ensures a high level of participation. Nonetheless, as major characteristics of the ICOS RI is standardization and data quality, all ICOS ES, either Class-1 or Class-2, are characterized by a strict standardization of instrumentation and procedures, and consequently the same level of data quality.

There is a possibility to establish ICOS ES Associated sites. The data from these sites are processed within the ETC database. The requirement is to submit at least one full year of data that must include a set of key variables with full description and meta-information, with the acceptance of the ICOS data policy. The associated sites receive ICOS-Associated status.

5.1.3 Marine observations

The marine network is based on instrumented “Voluntary Observation Ships (VOS)”, fixed time series stations and repeat sections. The VOS are usually commercial ships operating regularly repeated routes, e.g. ferry routes in European shelf and marginal seas, and cargo vessels on open marine routes. For the fixed time series, observations are recorded by means of moorings. These platforms need visits of well-equipped research vessels (like those in EUROFLEET), preferentially 4 to 12 times a year.

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

Repeat-section measurement campaigns are performed on research vessels from four times to once a year, depending on the dynamics of the area. All sections are measured to full depth to follow also the changes in the marine mixed layer, the general mixing as well as the ecosystems and marine current CO_2 transports.

5.2 ICOS Central Facilities

The ICOS RI is based on a network of stations that are highly standardized and coordinated. The Thematic Centers for atmosphere, ecosystem and marine observations (ATC, ETC and OTC, see section 4) and the Central Analytical Laboratories (CAL) are fundamental to ensure that these characteristics of the network are respected and maintained. The hosting countries of the ATC are France and Finland; of the ETC Italy, Belgium and France; of the OTC Norway and UK, and of the CAL Germany.

The ICOS CFs are needed to ensure that all data are treated and quality controlled with the same algorithms and properly archived for the long term. ATC, ETC and OTC receive online data from the ICOS stations on typically daily ba-

sis (near-real-time, NRT). They interact with the MSAs (see section 4), that consist of the station principal investigators, researchers and technicians, on matters related to coordination and improvement of the ICOS National Networks.

Besides data processing, there is a built-in complementarity between the ATC, ETC and OTC and the ICOS National Networks. The stations receive permanent support for optimal operation during their lifetime in the form of spare instruments, training and technical assistance. This also guarantees that new sensors can be smoothly implemented in the network.

ATC, ETC and OTC have frequent interactions with each other for coordination issues, sensors inter-operability, standardization in the data archiving, data formats and processing methods. Interaction with research institutions and industrial partners is maintained for stimulating new measurement methods and sensor development. It is important that only consolidated and fully-tested equipments/methods are used within the ICOS RI with the aim to maintain the state-of-the-art technology. As the life-time of the ICOS RI is long (>20 years), a key feature is the possibility to dynamically implement technological and state-of-the art scientific upgrades, by introducing new techniques, instruments and observed variables. The CFs will promote technology transfer in particular towards local spin-off companies.

5.2.1 Atmospheric Thematic Center

The ATC will receive online data from all ICOS Atmospheric Stations typically on a daily basis. It will ensure a rapid, smooth and traceable processing of the data collected by the atmospheric network. The ATC will develop automated quality control procedures that flag erroneous and questionable data points. It will also provide the tools needed for the visual inspection and final validation of the data. The ATC will provide the World Data Center for Greenhouse Gases and other data users with specific needs, with a coherent and documented dataset for all the ICOS Atmospheric Stations. In general, the ATC is responsible for the coordination of atmospheric measurements (continuous and discontinuous air sampling), instrument testing and validation, data processing and training. Data products include different levels of data, following application of successive quality control (QC) and processing steps. The ATC will regularly transfer sets of ICOS observational data to the Carbon Portal.

5.2.2 Ecosystem Thematic Center

The ETC is responsible for the on-line processing of data on net ecosystem fluxes and its components, carbon pools and other auxiliary data, and instrument development in co-operation with the wider community. The ICOS Ecosystem Stations submit daily data subsets for on-line quality checks to the ETC and provide NRT flux and meteorological data. They submit the raw data on monthly basis. This data is not corrected and cannot be used for most scientific purposes but can be useful for e.g. demonstrations and training. As for the ATC, different processing hierarchies are used for production of the various data sets resulting in different data levels that are under harmonization with other international activities. In general, there will be multiple levels of data indicating different processing steps and QC. Also ancillary information about the sites, e.g. metadata, vegetation and soil characteristics, disturbances and management, will be processed to ensure high standardization between the different sites. Protocols will be continuously updated and QA/QC procedures developed and applied to the ancillary data (see section 7). Soil and vegetation samples will be analysed in the ETC and stored for 20 years. The ETC will regularly transfer sets of ICOS observational data to the Carbon Portal.

5.2.3 Ocean Thematic Center

The OTC is responsible for co-ordinating continuous marine observations and initial data processing from the marine network. It provides support to the marine network in the form of information and technical backup on the state-of-the-art instrumentation and analytical methods. It provides data storage, data reduction techniques and quality control.

The OTC will support observations in the North Atlantic, Nordic Seas, Baltic and Mediterranean. As the observation of CO_2 fluxes is of global concern, the OTC also works with the global observing community to further the development of a network of global observations. The OTC will consequently support appropriate observations in marine areas other than the North Atlantic as observing platforms extend beyond the core ICOS area. The OTC will work with the wider community to develop new sensors for the carbon system for autonomous platforms, for providing better coverage of more remote areas. Complementary sub-surface observations will be obtained via co-operation with the hydrographic community. The OTC will regularly transfer sets of ICOS observational data to the Carbon Portal.

5.2.4 Central Analytical Laboratories

The Central Analytical Laboratories (CAL) are responsible for providing calibration gases for the atmospheric station network and analysis of flask samples for the entire network for components that are not measured continuously at the stations (such as stable isotope ratios of CO_2 and CH_4 or radiocarbon (^{14}C) for

estimates of fossil fuel CO_2). The processing of the atmospheric measurements at the ATC is based on the raw data gathered from the stations and on the calibration information provided (and regularly updated) by the CAL. Any revision of the calibration scale established by the CAL is propagated down to new versions of the lower level data processed by the ATC.

The CAL activities include the operation of a central Flask and Calibration Laboratory (FCL) and a Central Radiocarbon Laboratory (CRL) for the analysis of $^{14}CO_2$ samples. An additional responsibility of the CRL is the provision of specific sampling equipment to the ICOS AS for routine measurement of integrated air samples as well as the development of improved methodologies to determine fossil fuel CO_2 in the ICOS National Networks.

6. ICOS ERIC elements

6.1 Carbon Portal

The Carbon Portal (CP) acts as the platform for observational data and elaborated data products of the ICOS RI. The hosting countries of CP are Sweden and the Netherlands.

All relevant ICOS data and ancillary data sets from external sources will be accessible through the facilities of the CP. The CP shall provide a "one-stop shop" for all ICOS data products. As such, the CP is envisioned as a virtual data center, i.e. a place where ICOS data can be discovered and accessed along with ancillary data and where users can post elaborated data products that are obtained from the ICOS data. The CP will also have the ability to address all the requirements stemming from these aspects, including i) data security, ii) enforcement of the ICOS data policy and iii) user-friendly (and machine-friendly) internet-based and other computer-network-based interfaces.

The CP is developed based on standard data interfaces to be an integrative access point for all ICOS users, ranging from experts to stakeholders and the general public. The CP supports standardized data exchange protocols and techniques. The CP provides the capability of advanced service composition techniques for web-based distributed processing of ICOS data to generate useful information (e.g. risk maps and integration and analysis with other types of datasets) for research, public users and decision-makers.

In this context the CP will promote and support the production of elaborated products by scientific communities from the ICOS data. These will be distributed via the CP interface.

Organizing the long-term archiving of ICOS data products with the aim to both guarantee safe storage and future access, also after a possible cessation of the

Research Infrastructure itself, is an important task of the CP. This activity complements the data storage and backups routinely performed by the ATC, ETC and OTC. Decisions regarding the archiving strategy should be taken by the ICOS RI in consultation with the ATC, ETC and OTC and MSAs.

The ICOS RI endorses the general data sharing principles that have been defined and outlined by GEOSS*: i)* There will be full and open exchange of data, metadata and products, recognizing relevant international instruments and national policies and legislation; *ii)* All shared data, metadata and products of the ICOS RI will be made available with minimum time delay and at minimum ('reproduction' only) cost.

6.2 Head Office

The HO coordinates the ICOS RI at the European level. The hosting countries of the HO are Finland and France.

The main HO services include: i) Strategic scientific and technical planning and coordination, ii) Management of the legal entity and iii) Community building, outreach, promotion and training. The HO facilitates the work of the Director General (DG), the ICOS RI Committee and the General Assembly (GA). The HO assists the planning and facilitates scientific and technical objectives of the ICOS RI. The HO shall have the staff to take care of several duties and activities: most importantly legal issues, procurement and dissemination in order to meet public needs for specifically tailored products.

The HO promotes the network extension to new countries in cooperation with the ICOS CFs and the MSAs. The HO also supports science and technological development in the ICOS RI. As the main guardian of the ICOS legal entity, the HO also works for building general ICOS identity, securing that ICOS as a distributed RI, will operate as a strong productive actor both at the European and global level. The HO facilitates outreach as well as training and mobility of participants. The HO uses state-of-the-art management methodology and processes to ensure good governance, control and coordination, and high impact of the ICOS RI.

7. ICOS RI Quality Strategy

Data quality is critical to the success of the ICOS RI and therefore a Quality Assurance and Quality Control (QA/QC) system is developed for the ICOS RI. The ATC, ETC and OTC collect data and process it in a standardized way. Data need to be consistent, comparable and of known and adequate quality. In this process of quality management two types of auditing are required: auditing by an external body and audits by internal staff trained for this process. The aim is a continual process of review and assessment, to verify that the system is work-

ing as envisioned, to find out where it can be improved and to correct or prevent identified problems.

Issues critical to ensuring high quality are i) Use of standardized equipment; ii) Training of station personnel; iii) Measurement guidelines (MGs) and standard operating procedures (SOPs). The description of data quality objectives (DQOs) is important for instrument selection and development of MGs and SOPs.

The principal investigators (PIs) of the ICOS stations are responsible for quality assurance at the station and the first order quality control of the data. QA protocols developed by the ATC, ETC and OTC in cooperation with the associated MSAs have to be used. Station PIs, the ICOS Central Facilities and ICOS Quality Management Committee are responsible for ICOS internal quality control, which includes sampling and measurement system performance checks at the stations, standardized data processing and flagging, and calibration. Visits to stations will be made to check compliance to the ICOS standards and determine ways to improve quality. External quality control is done by an independent organization (i.e. external to the ICOS RI). External quality audits generate credibility to the ICOS data.

8. Embedding the ICOS RI into other European and global networks

The ICOS RI is one of several ESFRI initiatives in the environmental science domain. There is significant potential for structural and synergetic interaction with several other initiatives. The ICOS RI is an active player in developing the European environmental research infrastructures landscape and a European atmospheric observation system. The ICOS RI will have close collaboration with several European atmospheric and ecosystem observation networks, such as InGOS, ACTRIS and ANAEE and ESFRI projects such as IAGOS. The ICOS RI also participates in several joint ESFRI environmental domain projects, especially on developing common information and communications technology solutions for easier data discovery and ensuring better interoperability among environmental research infrastructures, both in Europe and globally. The ICOS RI is also relevant for Joint Programming, especially for JPI Climate, JPI Ocean and JPI Urban by providing data access for researchers and acting as a contact point for developing joint strategic research agendas among European member states.

The ICOS RI will be integrated into other worldwide atmosphere, marine and ecosystem observation programs. The list of variables covered in the ICOS RI matches that which GEOSS (Global Earth Observation System of Systems) has recommended to ‘support the development of observational capabilities for Essential Climate Variables such as CO_2, CH_4 and other greenhouse gases’, according to the 10-years GEOSS implementation Plan. The ICOS RI will also contribute to the WMO Global Atmosphere Watch program, to

GMES/Copernicus (the European Earth Observation Programme), to the Global Terrestrial Observing System (GTOS) and to the international Integrated Global Observing Strategy for Atmospheric Chemistry Observations (IGACO) and for the GEO Carbon Strategy under the GEO umbrella. TCCON (Total Carbon Column Observing Network) is a network of ground based remote sensing and its integration to the ICOS RI is very relevant. Marine observations are linked to the work of the International Ocean Carbon Coordination Project (IOCCP).

As the Carbon Portal also produces elaborated data products, the ICOS RI has an important role in development and synthesis work of carbon and nitrogen cycle models in the global arena.

9. Specific ERIC requirements relating to RI

9.1 Necessity

Sources and sinks of GHG and other relevant species are quantities that vary at a variety of scales that extend well beyond national boundaries. In order to capture the regional variability of sources and sinks, the measurements need to be distributed inherently at the continental scale with the stations of the networks being as representative for different European regions as possible, and focused over hot spots that are not always restricted to national entities.

Because the endeavour of climate mitigation through reduction in emissions and carbon capture technologies is currently tackled at the European scale, implementation of integration of measurements is required. The corresponding infrastructure needs to be backed by strong central facilities with a strong expertise and state-of-the-art equipment. This integration at the European level also facilitates the extension to neighbouring areas such as Russia, African countries, Middle East, etc. where the network also needs to be deployed for the benefit of all scientists in Europe and these countries. The ICOS RI is open to expand its observation network beyond the European domain through bilateral cooperation with other networks under the condition that enough resources become available for implementation on both sides.

9.2 Strengthening and structuring of the European research area (ERA)

The ICOS RI will strengthen the position of Europe as a global player for *in situ* observations of greenhouse gases, data processing and user-friendly access to data products for validation of remote sensing products and in scientific assessments, modeling and data assimilation. The ERA benefits from the ICOS RI, as it will strive toward the deployment and development of local infrastructure (monitoring sites) in each country. The ICOS RI enables easy participation of new European member countries with small investments necessary to get involved, thus increasing the European collaboration.

The ICOS stations and measurement procedures can be utilized together with other communities, such as aerosol research, integrating GHGs to other climate forcings. Thus, a new generation of scientists will emerge using e.g. GHG and aerosol data together toward new scientific discovery, reanalysing long and consistent time series not yet available, with integrated data model fusion tools that are currently in their early development stage and will benefit from this activity. Weather forecasting and Earth observation (Copernicus) benefit from the ICOS RI. The joint MoUs (Memorandum of Understanding) will be used to formalise relationships. A key institution using the ICOS data is the European Center for Medium range Weather Forecast (ECMWF). Socio-economic impacts include a better knowledge and independent estimation of GHG sources and sinks and new measurements contributing to air quality over Europe. IPCC panel members will have access to unique, high precision long term data to understand the carbon cycle and the current perturbation attributed to anthropogenic activities.

European innovation is promoted through relation with European SMEs and technology groups who aim in parallel at developing instruments (providers to the infrastructure) and services to the public and policy makers (users of the infrastructure). The smart use of intellectual property developed in the ICOS RI will give European companies or spin-off companies a competitive edge in climate services related to mitigation efforts. The following categories of users have been identified:

- ICOS RI will allow the European scientific instrumentation industry to benefit from a worldwide demonstration platform. The ICOS RI will help companies specialized in the manufacture of environmental equipment to integrate the proper instrument characteristics (such as sensitivity and measurement precision, size, portability, handiness and robustness) within the constraints of production engineering.
- ICOS RI will enable the agricultural and forest sectors to adapt their practices to reduce their GHG emissions and optimize ecosystem services. Indeed, the ICOS RI will provide field-compliant GHG monitoring tools, allowing real-time monitoring, and will help to enlarge the range of methodologies and practices (*e.g.* fertilization, irrigation, manure and waste management, soil management, harvest practices and forestry practices) that will help to optimise ecosystem services production in agriculture and forests.
- ICOS RI will produce valuable data for the services sector such as carbon accounting companies and the environmental, waste management and renewable energy sectors. The ICOS data will also represent a unique source of environmental data for companies specialized in energy reporting and carbon accounting.
- All data and ICOS products will be available freely for educational purpose and related SMEs involved in education. Beyond data products, the measurement sites of the ICOS National Networks in marine, atmosphere and terrestrial ecosystems will be available for supporting educa-

tional activities such as class visits, school-science networking projects and web assisted teaching.

Examples of the SMEs linked to the ICOS RI are: InSitu (http://www.insitu.se/) involved in implementing instrumentation of the kinds that the ICOS RI uses and using ICOS-Sweden stations as a "test facility" for new technology; IVL Svenska Miljöinstitutet (http://www.ivl.se/), a semi-private research institute/company, interested in using ICOS data products; FastOpt (http://www.fastopt.com/), a consulting company on geosciences utilizing ICOS data; HEURISTICA OU (http://www.salespider.com/bw-12208265/heuristica-ou), a spin-off company stemmed from carbon cycle research devoted to commercial physical and biological research; SUVILUMI (www.suvilumi.fi), a spin-off company stemmed from ecosystem research devoted to atmospheric measurement services for industry and research; EMS Brno (http://emsbrno.cz/p.axd/en/Main.Page.html), small private company cooperating with research institutes and universities and producing meteorological and forestry sensors and data loggers, already accepted for the ICOS ecosystem measurements.

9.3 Effective access

The ICOS RI will provide access to a broad suite of data products and services including standards, calibration, protocols, instrumentation, software, information on essential climate and ecosystem variables, and support to environmental policies. An ICOS user may be a person, organization, program, initiative, protocol, energy utility or business. An ICOS user is any entity who is interested in using any of the ICOS products. Core users include researchers and students. The main products and services provided to these groups by the ICOS RI are access to data and access to research infrastructure and training. If research access to the ICOS RI facilities and services has to be restricted for capacity reasons the selection criteria shall be based on scientific excellence. The selection criteria for training access shall be based on the needs of the special groups, topicality and suitability. The percentage of access for users not belonging to the ICOS ERIC members or observers varies from low (ca. 10 % for training schools) to high (ca. 50 % for global scale data analysis).

The users potentially interested in the ICOS products and services belong to a wide variety of entities, ranging from science to policy, from the public to the private sector, from mass media to operational monitoring agencies. Additionally any entities that need external independent verification will benefit from the ICOS data. The following categories of potential users can be distinguished: *i)* National and international scientific programs and environmental agencies that monitor carbon cycle or relevant data; *ii)* Operational and pre-operational service providers of carbon fluxes; *iii)* Regional authorities; *iv)* Protocol verification bodies; *v)* Scientific communities devoted to nitrogen cycle, other trace gases, aerosol particles and weather forecasting; *vi)* Remote sensing communities; *vii)* Private sector; *viii)* Educational organizations.

9.4 Mobility

The ICOS RI contributes to the mobility of knowledge and/or researchers within the ERA. It increases the use of intellectual potential throughout Europe and supports development of technology and protocols for high-quality and cost efficient measurements of GHG concentrations and fluxes applicable and promotable also beyond Europe. The ICOS measurement sites offer platforms for detailed field studies on atmospheric, marine and eco-physiological processes, where the demand for supporting and auxiliary measurements and observations is huge. They can be also utilized as test sites for new instruments and sensors, offering the representative range of climate and geographical regions, needed for comprehensive field testing. Training (summer schools, workshops, intensive field work campaigns) on ICOS measurements is organised, paying special attention to research groups establishing their first measurement sites. The possible restrictions and selection criteria for mobility follow general access rules, specifically adopted for research access and for training.

9.5 Dissemination

The ICOS RI dissemination and communication plan describes the approach for how the ICOS results are disseminated and communicated, and how the ICOS RI internal communication is organised. The ICOS RI actively distributes research results through publication in peer-reviewed journals and on the ICOS RI web site, and by organizing and participating in conferences and workshops. Dissemination through the highest impact journals, such as Nature, Science, Nature Geoscience, Nature Climate Change, is encouraged. The ICOS RI has been initiated and is being implemented by a strong and committed consortium of scientists that roots in excellent science and cooperation over the last 20-25 years. The main task of the ICOS RI is to make sure that the crucial observational data is disseminated to the scientific community and society in which the RI itself takes part. Both the platform for elaborated products offered by the Carbon Portal and the activities of the CFs will encourage and support co-operation between research groups, inside and outside the ICOS community, and make use of ICOS data products. The elaborated data products will also be essential basis for the aggregated syntheses that are relevant for policy makers and the general public. Education and training curricula are updated using the latest knowledge and technology.

Knowledge dissemination is also a key to raise the public awareness on the infrastructure itself, greenhouse gases and climate change. The mass media and the general public seek explanations from scientists but they also like to analyze data and facts by themselves; a basis of “citizen science”. As such the interest for the ICOS data extends beyond expert communities. Mass media are looking for better, more accurate and up-to-date information about global change and its implications for communities. The general public (i.e. any individual that wants to know about GHG emissions or absorption in Europe) wants to understand better how Earth - our planetary life-support system - is evolving over time.

Specific information products will be tailored to these different users. For example, there exists an expressed need for consultation products targeted to policy makers, in order to facilitate environment oriented policy decisions. Similarly, a synthesis of recent findings emerging from the ICOS data could be produced every year and distributed to the whole users' community, considering implications for all possible uses, such as for policy and education.

A wider stakeholder community will be engaged in the ICOS RI, including e.g. the private and public sectors and non-governmental organisations (NGOs) operating in relevant fields. Consultation with the stakeholder user-groups on the design of the observation program and on the integrated flux products is important. Outreach to the general public through lectures, popular science articles, internet blogs, twitters and documentaries broaden the public´s perspective on the carbon cycle and effects of GHGs, and help to improve the common understanding on key human and natural processes. The ICOS RI includes a training component broadened beyond the ICOS community, to e.g. environmental agencies, regional authorities, private sector and educational organizations. Within the collaboration network of the public sector, new applications of the ICOS data are envisioned, like assessments and estimates of ecosystem services. Easy-to-use analysis methods and services are being developed, which will enable estimations of costs related to climate change as well as evaluation of the concrete impacts of the ICOS RI in the mitigation of climate change. In order to facilitate wider access to the ICOS RI and ICOS data products, web-site content will be made available also in other languages than English.

ABBREVIATIONS

^{14}C	Radiocarbon
$^{14}CO_2$	carbon dioxide containing a radioactive carbon isotope
ACTRIS	Aerosols, Clouds, and Trace gases Research InfraStructure Network
ANAEE	ESFRI Research infrastructure project for experimental manipulation of managed and unmanaged terrestrial and aquatic ecosystems
ATC	ICOS Atmospheric Thematic Centre
CAL	ICOS Central Analytical Laboratory
CH_4	Methane
Class-1 station	(for ecosystem and atmospheric stations) complete equipment for measuring the full set of ICOS core parameters
Class-2 station	(for ecosystem and atmospheric stations) same analytical precision as Class-1 station but less physical parameters measured
CO	carbon monoxide
CO_2	carbon dioxide
CP	ICOS Carbon Portal
CRL	Central Radiocarbon Laboratory of CAL
DG	ICOS ERIC Director General
DQO	Data Quality Objectives
Earth System Models	sets of equations describing processes within and between the atmosphere, ocean, cryosphere, and the terrestrial and marine biosphere
EC	European Commission
ECMWF	European Center for Medium range Weather Forecast
ERA	European Research Area
ERIC	European Research Infrastructure Consortium
ES	ICOS Ecosystem Station
ESFRI	European Strategy Forum on Research Infrastructures
ETC	ICOS Ecosystem Thematic Centre
EUROFLEET	Towards an Alliance of European Research Fleets
FCL	Flask and Calibration Laboratory of CAL
GA	ICOS ERIC General Assembly
GCOS	Global Climate Observing System
GEOSS	Global Earth Observation System of Systems
GHG	Greenhouse gases
GTOS	Global Terrestrial Observing System
HO	ICOS Head Office
IAGOS	In-service Aircraft for a Global Observing System
ICOS AS	ICOS Atmospheric Station

ICOS CF	ICOS Central Facilities that are ATC, ETC, OTC, CAL and CP
ICOS ES	ICOS Ecosystem Station
ICOS National Networks	ICOS ERIC Member countries' AS, ES and marine networks of stations and observations
ICOS RI	Integrated Carbon Observation System Research Infrastructure
ICOS RI Committee	ICOS Research Infrastructure Committee
InGOS	Integrated non-CO_2 Greenhouse gas Observation System
IOCCP	International Ocean Carbon Coordination Project
IPCC	Intergovernmental Panel on Climate Change
JPI	Joint Programming Initiative (e.g. JPI Climate, JPI Ocean)
KPI	Key Performance Indicator
MG	Measurement Guidelines
MSA	Monitoring Station Assemblies for ICOS ERIC Member countries' AS, ES and marine networks
N_2O	nitrous oxide
NGO	Non-Governmental Organization
NRT	Near-Real-Time
OTC	ICOS Ocean Thematic Centre
pCO_2	partial pressure of CO_2 in the atmosphere and the ocean
PI	Principal Investigator of measurement station(s)
QA/QC	Quality Assurance and Quality Control
RI	Research Infrastructure
RoP	Rules of Procedures
SAB	Scientific Advisory Board
SF_6	sulfur hexafluoride
SME	Small and medium enterprises
SOP	Standard Operating Procedures
TC	Thematic Centers for atmosphere, ecosystem and marine observations (ATC, ETC and OTC)
UNFCCC	United Nations' Framework Convention on Climate Change
VOS	Voluntary Observation Ships
WMO	World Meteorological Organisation