D17.6 White paper on further integration of RIs in the environmental field including recommendations on co-locating research sites at national and international level

WORK PACKAGE 17

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Abstract

This study provides basic information to support a strategy for further integration of European Environmental Research Infrastructures (ENVRIs). The approach that has been first successfully developed for the ENVRIs in the terrestrial ecosystem domain (Kutsch et al. 2017; ENVRIPLUS deliverable 12.3) has here been extended to the atmosphere and the marine domains. The respective 'domain studies' are provided as appendices.

The overall aim is to push the common reflection one step forward. Based on the domain studies provided here and in Kutsch et al. 2017, an analysis of the current landscape and a group of possible scenarios for reinforced cooperation between RIs is developed. The target is a situation that would benefit all parties and strengthen their positions, be it in terms of scientific expertise, relevance of their products and services, or societal impact.

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PROJECT SUMMARY
ENVRIPLUS is a Horizon 2020 project bringing together Environmental and Earth System Research Infrastructures, projects and networks together with technical specialist partners to create a more coherent, interdisciplinary and interoperable cluster of Environmental Research Infrastructures across Europe. It is driven by three overarching goals: 1) promoting cross-fertilization between infrastructures, 2) implementing innovative concepts and devices across RIs, and 3) facilitating research and innovation in the field of environment for an increasing number of users outside the RIs.
ENVRIPLUS aligns its activities to a core strategic plan where sharing multi-disciplinary expertise will be most effective. The project aims to improve Earth observation monitoring systems and strategies, including actions to improve harmonization and innovation, and

generate common solutions to many shared information technology and data related challenges. It also seeks to harmonize policies for access and provide strategies for knowledge transfer amongst RIs. ENVRIPLUS develops guidelines to enhance transdisciplinary use of data and data-products supported by applied use-cases involving RIs from different domains. The project coordinates actions to improve communication and cooperation, addressing Environmental RIs at all levels, from management to end-users, implementing RIstaff exchange programs, generating material for RI personnel, and proposing common strategic developments and actions for enhancing services to users and evaluating the socioeconomic
impacts.
ENVRIPLUS is expected to facilitate structuration and improve quality of services offered both within single RIs and at the pan-RI level. It promotes efficient and multi-disciplinary research offering new opportunities to users, new tools to RI managers and new communication strategies for environmental RI communities. The resulting solutions, services and other project outcomes are made available to all environmental RI initiatives, thus contributing to the development of a coherent European RI ecosystem.

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1 Introduction

1.1 Background and motivation

"Tackling environmental challenges is crucial for mankind and for life on Earth and given the scale, complexity and the interlinkages of the challenges, a multidisciplinary approach is essential. Layers of complexity to carrying out environmental research are added by the multidisciplinary aspect amongst the main Earth system domains and by the considerable range of spatial and temporal scales involved. Because of its complexity, the environmental research as a whole should be facilitated by comprehensive observations with an integrated approach including experiments and modelling which are essential for understanding and predicting the Earth's environmental system."

ESFRI Roadmap 2018, Part 2: Landscape Analysis

The recent years have seen the setting up of several global frameworks to tackle the major challenges of our times. For example, the United Nations' Agenda 2030 for sustainable development has established the 17 Sustainable Development Goals (SDGs) that should guide the actions of the international community towards a better shared future by 2030. The Paris Agreement addresses the specific threat of climate change and its consequences for future life on Earth. The Sendai Framework for Disaster Resilience aims to help societies, and especially the most vulnerable ones, prevent or overcome severe disasters that might otherwise devastate them.

Implementing these global frameworks calls for cooperation of a large number of actors. Countries and governments at the forefront, but also businesses, municipalities, and individuals must get together to find and implement the necessary solutions. This is especially true in the field of environmental sciences, as the current threats are global and will only be mastered by strong multilateral global cooperation. In this context, research infrastructures (RIs) have become key to facilitate high-impact research and foster innovation, by joining forces internationally and in a coordinated and sustained manner. At the same time, resources are often scarce or very unevenly distributed. This imposes a particular constraint on the funding of research activities in almost all regions of the world. Europe is not spared by this pressure and it is no surprise that the institutional framework in which RIs are evolving tends to exhort them to closer cooperation, enhanced synergies, or even further integration.

In order to assess the current situation of the European Environmental RIs (ENVRIs), this study continues the thorough work of analyzing the ENVRI landscape with detailed descriptions of its scientific domains. Several reports have been written, under the ENVRIPLUS project, to describe these domains in details. Some are part of this document as appendices. In these reports, special attention has been given to the core competencies of the RIs, the Grand Challenges they address, the Essential Variables they measure, the relations they have to the global frameworks mentioned before, the services and products they provide, their complementarities, collaborations and user communities, as well as their roles within national roadmaps. As a final product of the ENVRIPLUS project, this document summarizes the essential messages of these reports and provides conclusions to support the further development of a common ENVRI cluster strategy which has to develop strong and convincing answers to a question that is implicitly asked for in the ESFRI Roadmap text cited in the beginning of this paragraph:

How can an integrated approach of observations, experiments and modelling which ensures all essential elements for understanding and predicting the Earth's environmental system be provided in the most synergistic, resource-efficient and user-friendly way?

1.2 Scope of this report

To answer the abovementioned question, the present paper leans on domain-specific reports and aims to push the common reflection one step forward. Based on the analysis of the current landscape, it explores a group of possible scenarios for reinforced cooperation between RIs. The target is a situation that would benefit all parties and strengthen their positions, be it in terms of scientific expertise, relevance of their products and services, or societal impact. However, it cannot be ignored that the European RIs have evolved and will further develop in a highly competitive and highly variable funding situation which makes cooperation difficult. It has even been said that the unsustainable funding system and the lack of clear funding processes has created a collection of "egosystems" instead of a landscape of individually sustainable ecosystems where everyone contributes to a common endeavor. Thus, this report aims to support the ENVRI community in sharpening its strategy of cooperation but also to support developments of political orientations at the national or European level that hopefully ensure the sustainability of the research infrastructures. The authors think, thus, that the better the analysis and the evaluation of possible scenarios, the easier the adaptation will be.

1.3 European research infrastructures in the environmental field

The European Union has been a forerunner in consistently establishing and supporting RIs. The work of ESFRI has led to a situation where most of the countries in Europe now have or are developing a national roadmap for RIs, very often to guide their investments. This process has been particularly successful for environmental RIs and gives Europe a strong worldwide position in this scientific field. Consequently, the ESFRI Roadmap contains 11 environmental RIs (7 Landmarks and 4 Projects). In addition, the ENVRI community has included a number of communities that have developed stable enough structures to fulfil the characteristics of the ESFRI Roadmap 2018: long-term research facilities of pan-European importance that are necessary to strengthen the scientific excellence and competitiveness in the EU. This enlarges the number of ENVRI members to more than 20. This broader approach goes well along with the scope of this analysis since it needs to reflect the broader landscape (beyond the ESFRI roadmap) in order to support further cooperation and integration. There are indeed several reasons for RIs to be missing on the ESFRI roadmap. For instance, the RI can still be in the process of building a tighter scientific community, funded by the European Commission as Integrating Activity or at the beginning of the preparation phase as Design Study (for the development of a new pan-European RI) and not have reached the maturity to be listed. Or, the RI may lack the pan-European dimension that is required for ESFRI Landmarks or national roadmap processes. It can also miss political/financial commitments to enter the ESFRI process (the RI is trapped in an eternal project cycle) or suffer from non-recognition of specific legal entities.

For the purpose of clarity, the ENVRI cluster has been split into different domains which are separated somehow spatially (atmosphere, land surface, ocean and freshwater bodies, and deep earth). The ESFRI Roadmap 2018 has named these domains 'spheres': Atmosphere, Biosphere, Hydrosphere, and Geosphere, which is problematic, since life (biosphere) extends to all other spheres while water (hydrosphere) is part of every living being and pervades the other spheres e.g. as air humidity, clouds or soil moisture. While discussions are still ongoing, this study uses in a practical approach 'Atmosphere domain', 'Terrestrial Ecosystems domain', 'Marine domain' and 'Solid Earth domain'. In addition, we are fully aware that there are manifold interrelations between the domains, which are important to be considered. Alternative approaches such as the cycle approach (e.g., carbon cycle, nitrogen cycle; water cycle), are realized by single RIs (e.g. ICOS) but not appropriate for describing the entire ENVRI cluster yet. Another alternative approach related to Grand Challenges has been provided by ENVRIPLUS deliverable D12.1.

The ENVRI community has been illustrated during the lifetime of the ENVRIPLUS project according to the domain approach (Fig. 1) where the four domains are located around a multi-domain area. Some RIs are clearly single domain infrastructures such as ACTRIS, IAGOS and EISCAT 3D for the atmosphere while others ore clearly multi-domain such as ICOS or LifeWatch. However, the illustration reaches its limits when RIs touch the interface between two domains such as DANUBIUS RI in estuaries or EMSO ERIC in the deep sea.

FIGURE 1: ILLUSTRATION OF THE ENVRI CLUSTER/ LANDSCAPE as used throughout the project. The symbols of the RIs are located within the four domains or in the multi-domain center. The grey area symbolizes the ESFRI Roadmap.

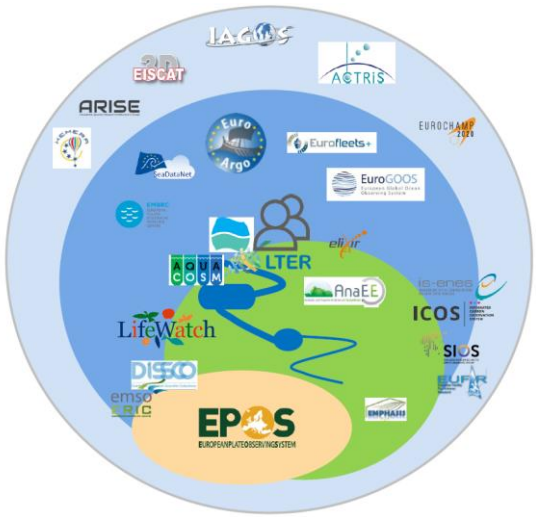

FIGURE 2: A FIRST SKETCH OF THE UPDATED ILLUSTRATION OF THE ENVRI CLUSTER/ LANDSCAPE.

The shape of the two people in the center represents the societal dimension that is considered by many RIs as well.

A new illustration of the ENVRI community has been developed in the framework of this task. It enables to better locate the RIs as either clearly within or at the interfaces of the spheres and to distinguish between oceans and freshwater. The sketch will be further developed during the update of the ENVRI strategy beyond ENVRIPLUS and for the development of the next ESFRI landscape analysis.

2 Portfolio of core competences and identification of gaps

The ENVRI landscape is defined by the scientific scopes and the core competences of the RIs. It is important that these are clearly defined and overlap is avoided. Table 1 describes the RIs that have been considered in this study.

Table 1: Scopes and core competences of the RIs in this study.

Name of the RI	Domain (A, B, G, H)	Brief description of scientific scope	Core competences
ESFRI LANDMARKS			
EISCAT_3D	A	Observe the atmosphere and near-Earth space environment above the Fenno-Scandinavian Arctic to investigate how the atmosphere is coupled to space.	– Continuous (daily) 3-D incoherent scatter observations of the state of the upper atmosphere and ionosphere above the northern Scandinavian peninsula (altitude above the range of aircraft and balloon measurements and below the range of most satellite measurements; independence of cloud coverage, weather conditions and space weather events) – Improvement of more than an order of magnitude in the temporal and spatial resolutions of ionospheric observations compared to present EISCAT system – Wide range of additional applications, e.g., supporting solar system and radio astronomy sciences, space weather forecasts, detecting space debris…
ELIXIR	H	Coordinate and develop life science resources across Europe so that researchers can more easily find, analyse and share data, exchange expertise, and implement best practices, in order to gain greater insights into how living organisms work.	– Coordinating and developing life science and bioinformatic resources across Europe, including databases, software tools, training materials, cloud storage and supercomputers – Uniting Europe's leading life science organizations in managing and safeguarding the increasing volume of data and knowledge – Supporting development of a sustainable metagenomics infrastructure with the potential to provide a broad range of industrial applications
EMBRC	H	Enable research to further our understanding of marine ecosystems and biodiversity, understand the impact of climate change on them, and develop sustainable exploitation of marine environments and ecosystems.	– Provide a portal to a comprehensive range of services, resources and knowledge in marine biology and ecology research (long-term ecological monitoring), key thematic areas include marine biodiversity, ecology, and ecosystem function, developmental biology and evolution, marine products and resources (biotechnology, aquaculture, fisheries), biomedical science, but also ocean acidification, biological oceanography

			– Unlock the potential of the marine realm for new biomaterials, develop scenarios for changing ocean, develop enabling technologies, standards and methods and support scientific breakthroughs and applications in medicine, nutrition and aquaculture – Develop and validate comprehensive approaches to study the water column and environmental monitoring, and deploy a network of augmented ocean observatories, including genomics, imaging… to complement the long-term data series in many EMBRC sites – Provide access clearance and facilitated procedures for researchers to marine genetic resources in compliance with the Nagoya Protocol and Access and Benefit sharing regulations
EMSO	H	Set up smart regional facilities (seafloor and water column observatories) and tools to monitor EOVs.	– Provide open ocean fixed point multidisciplinary observatories, from the sea surface (up to 1 m below sea surface) to sea-floor and sub-seafloor: observation of physical and environmental variables to understand complex interactions between the geosphere, biosphere and hydrosphere – Develop of new sensor technologies – Document and study episodic events which are difficult to detect by short-term marine expeditions, such as earthquakes, tsunamis, slope stabilities, hydrothermal vents, benthic storms, biodiversity changes, pollution, gas hydrate (methane) release, dense water cascades, plankton booms, water mass movements, influence of eddies…
EPOS	G	A long-term plan for the integration of national and transnational research infrastructures for solid Earth science	– Enable innovative multidisciplinary research for a better understanding of the Earth's physical and chemical processes that control earthquakes, volcanic eruptions, ground instability and tsunamis as well as the processes driving tectonics and Earth's surface dynamics. – Integrate data, models and facilities to allow the Earth science community to develop new concepts and tools for key answers to scientific and socio-economic questions concerning geo-hazards and geo-resources for a safe and sustainable society.
EURO-ARGO	H	Continuous monitoring and NRT data provision of the temperature, salinity, and velocity of the upper ocean.	– Argo is the first global in situ ocean observing network in oceanography: provides a global array of profiling floats measuring water temperature and salinity every 10 days to a depth of 2000 m, as important complement to satellite observations – Develop an increasingly dense array of biogeochemical measurements

IAGOS	A	Global measurements of atmospheric composition on a regular basis with focus on the tropopause region, which is most sensitive to climate change, and tropospheric columns.	– High-resolution atmospheric composition measurements (GHGs, reactive gases such as ozone and precursors, aerosols, cloud particles) – Long-term, regular vertical profiles over major cities and detection of long-term changes in the troposphere and lower stratosphere: UTLS layer (9-12 km altitude, critical with regard to GHG effect) – Deeper understanding of atmospheric chemistry and physics – Measurements with two systems installed on commercial aircrafts: IAGOS-CORE: fully automatic measurements of fixed set of variables onboard a growing fleet of aircrafts, quasi-global/quasi-continuous measurements (every day); IAGOS-CARIBIC: measurements of a large, flexible set of variables monthly during 4 flights of 1 aircraft
ICOS	A, B, H	Understand carbon-climate feedbacks and anthropogenic emissions of GHG	– Standardized, high-precision, continuous atmospheric concentration measurements of long-lived GHGs (CO_2, CH_4, N_2O and respective ancillary tracers) in the natural atmosphere from ground-based stations; – Standardized, high-precision, continuous measurements detecting GHG fluxes from terrestrial ecosystem and the ocean surface; – Quality assurance and control (based on globally operating procedures); – Multi-scale analysis of greenhouse gas emissions and carbon cycle with human and natural drivers, processes and controlling mechanisms, provision of global and regional budgets – Validation/uncertainty reduction in emission inventories and climate models
LifeWatch	B, H	Use and further develop the digital technologies and existing data and knowledge to bring together scientists, administrators and managers, politicians and common people. Provide them with the knowledge to understand the functioning of “Our Live Supporting System” and to develop actions to ensure its sustainability.	– Distributed virtual laboratory: Managing and providing access to a multitude of datasets as well as to data aggregation, analysis and modelling services – Provide services and tools enabling the construction and operation of virtual research environments (VREs) where specific issues related to biodiversity and ecosystem research are addressed, including research focusing on biodiversity and ecosystem conservation, ecosystem re-naturalization and re-construction – Facilitates and promotes changes in scientific practice towards big data synthesis – Access to aggregated data resources on marine biodiversity (genomic, trait, taxonomic and functional diversity) and marine ecosystem functioning, by integrating resources originally developed by different large and global scale initiatives (e.g., worms, GBIF, GEO) and resources developed within LifeWatch ERIC (e.g., gene, traits and morpho-functional trait data, species and habitat data and sets of ecosystem level information)

			– Marine-VRE for understanding on marine metagenomics, ocean carbon sequestration and acidification, ecological and environmental status assessment of marine environments
ESFRI PROJECTS			
ACTRIS	A	Observing aerosols, clouds and trace gases for air quality and climate research.	– Long-term, continuous observations for 135 short-lived atmospheric compounds in the natural atmosphere (remote sensing/ in situ), covering clouds (more frequent than the usual orbital remote-sensing data), aerosols, trace gases and precursors (supporting the aerosol and ozone ECVs) – Experiments in atmospheric simulation chamber (see EUROCHAMP)
AnaEE	B	Access to experimental platforms on terrestrial and aquatic ecosystems across Europe. Analytical and modelling platforms as well as acquired data are also made available.	– Ecology, agronomy, biochemistry, biophysics, microbiology using observation, experimentation, modeling and samples preservation. – Plant biomass characterization, taxonomic identification, CO_2 monitoring and climate change, marine biology and marine resources, social interactions
DANUBIUS	H	Enable and support research addressing the conflicts between society's demands, environmental change, and environmental protection in river–sea systems worldwide and support their sustainable development	– Facilitate studies of river-sea systems (RSS), addressing particularly the conflicts between societal demands, environmental change and environmental protection – Allow for analysis of the entire RSS (continuum) with focus on transitional zones, which are of special importance for society, and the development of management solutions – Bring together the fragmented, discipline-specific (natural science, socio-economics, engineering, etc.) and often geographically isolated European research on RSS (strongly interdisciplinary approach) – Harmonize and provide access to a range of European river-sea systems, existing facilities and expertise
DiSSCo		Data-intensive frontier research through unified access to European natural science collections	– Place science collections at the center of data-intensive research and innovation for taxonomic and environmental research, food security, health, and the bioeconomy – Mobilize, link and deliver currently fragmented biodiversity and geodiversity information at a scale, form and precision required

eLTER	B, H	Understand the multiple effects of global change in European major ecosystems and socio-ecological systems by site-based, multi-scale and cross-disciplinary research into ecosystem structures and functions.	– Hypothesis-driven long-term ecosystem research at a nested system of sites at multiple spatial scales: site-specific observations considering the specific needs – "Whole system approach" to observe and analyze the environmental system, encompassing biological, geological, hydrological and socioecological perspectives – Include a "Long Term Socio-economic and Ecosystem Research" (LTSER) component focusing on the direct societal relevance and the embedded tools to analyze features linked to societally-relevant properties (e.g. competing land uses, protection of recreational values, preservation of drinking water…)
EMPHASIS	B	Multi-scale phenotyping platform for food security in different agro-climatic scenarios	– Provide services related to plant phenotyping, mainly access to plant phenotyping facilities and competences – Analyze genotype performance under diverse environmental conditions – Quantify the diversity of traits contributing to performance in diverse environmental scenario – plant architecture, major physiological functions and output, yield components and quality.
OTHER RIs			
AQUACOSM	H	Strengthen EU network of mesocosm facilities and promote joint research activities, capacity-building and standardization in order to achieve a better understanding necessary to manage our future waters effectively.	– Network of aquatic mesocosms (ecosystem-scale experiments) that brings together the marine and freshwater research domains (from mountains to ocean: river, lakes, estuaries, coastal and open ocean, from the Arctic to the Mediterranean), integrating freshwater and marine communities also in direct standardized mesocosm-studies (joint research activities on coordinated pilot studies across salinity gradients, and geographical north south gradients) – Access to and harmonization between mesocosm facilities for ecosystem-scale experiments on marine and freshwater systems to obtain a quantitative understanding of ecosystem-level impacts of stressors in complex systems – Experimental manipulation studies/ scenario tests provide observational data for parameterization and evaluation of models (focus on climate change scenarios) – Provide facilities with unique and leading capabilities (open ocean mesocosm facility, highly instrumented aquatic facilities…) to do research on topics like ocean acidification, light pollution…

ARISE	A	Establish an atmospheric research and data platform in Europe, which combines a large set of complementary observations and modelling studies to better describe the dynamics of the middle and upper atmosphere.	– Integrate observations to a 3D image of large-scale atmospheric dynamics and disturbances (e.g., gravity waves and tides, regional stratospheric anomalies): infrasound, LIDAR, airglow, radars, ionospheric observations and satellites – Provide altitude range covering the middle and upper atmosphere where routine, high-resolution observations are rare in order to better describe the interaction between atmospheric layers in poorly sampled altitude ranges and capture the influence of large-scale atmospheric disturbances such as planetary and gravity waves, stratospheric warming or thunderstorm convection on the general circulation – Long-term datasets (LIDAR data and infrasound stations) to investigate broader scientific questions, e.g. effect of climate change (lightning, gravity waves), course of stratospheric temperature, location of ice-breaking in polar regions – Improve accuracy in short and medium-range weather forecast and climate models (temporal scales from several weeks to season) – Monitoring of distant volcanic eruptions in support of the civil aviation
EUFAR	A	Ensure that aircrafts and equipment are available across Europe for environmental research, guarantee efficiency in operation and (easy) availability of respective observational data (operational airborne environmental research).	– Providing access to research aircrafts as all-purposes experimental platforms allowing a broad portfolio of atmospheric observations and remote-sensing of land/water surfaces (e.g., land-surface interactions) – Access to remote areas and during periods when observations are rare (e.g., not covered by in-service flights), but critical to the understanding of particular physical, chemical or biological processes (e.g., for comparison with modelling studies)
EUROCHAMP	A	Significantly enhance the capacity for exploring atmospheric processes by utilization of atmospheric simulation chambers providing different (controlled) conditions for studying how a compound will be transformed in the atmosphere (changes in chemical and physical properties)	– Providing access to atmospheric simulation chambers allowing studies of the properties of atmospheric compounds, especially kinetics and mechanisms that govern ozone and photo-oxidizing species production, particulate matter formation – Providing data basis for parameterization of models – Providing advanced tools to elucidate processes in the atmosphere, e.g., understand chemical transformation, forecast properties, quantify secondary sources

EUROFLEETS	H	Coordinate (national) research vessel fleets in Europe, optimize the procedures, detect spare capacities and provide access to the facilities.	– Coordination of access to European marine research vessels and equipment, optimizing campaign schedules in view of the expensive ship time: user-driven application, from sea surface to seafloor – Development of a long-term vision for provision of pan-European TNA access – Development of tools and software for deep water exploration and research – Use of latest technologies for telepresence approach to deep water research
EuroGOOS	H	Promote operational oceanography in the European Commission and globally.	– Promote operational oceanography with a full value-chain approach: observations and integration towards fit-for-purpose products and services – Coordination of five Regional Operational Oceanographic Systems (ROOS) – EuroGOOS working groups, networks of observing platforms (task teams), and ROOS provide fora for cooperation, unlocking quality marine data and delivering common strategies, priorities and standards – Deliver strategies, priorities and standards towards an integrated European Ocean Observing System (EOOS) involving ocean health, real time services and climate observations
HEMERA	A	Facilitate atmospheric research by using stratospheric balloons (scientific fields: atmospheric chemistry/ dynamics, astronomy, technology, vertical profiles/ light instrument validation, meteorological phenomena in the earth and sea-atmosphere boundary layer).	– Providing access to stratospheric balloons, allowing user-driven application (infrastructure not confined to atmospheric measurements) – Balloons can be navigated, long-distance flights are possible, e.g. trans-Atlantic, circumpolar – Altitudinal coverage complements ground-based and satellite observations of trace gases, aerosols, clouds for chemical and dynamical questions
IS-ENES	A	Understanding and predicting climate variability and change with climate modelling, facilitating model development and supporting WCRP internationally coordinated climate simulations.	– Providing access to climate models and software tools for model development and use – Providing access to model data from global and regional climate models (CMIP and Coordinated Regional Climate Downscaling Experiment, CORDEX), including variables from atmosphere ocean, land in their physical and biogeochemical dimensions, for past, present and future climate conditions
JERICO	H	Provide observation and monitoring of the complex marine coastal seas with capabilities to deliver high-quality	– Integrating observations and competences in physics, biology and biogeochemistry of the marine coastal environment allowing an ecosystem approach from the bottom to the sea surface European network of coastal

		environmental data, provide access to solutions and facilities as services for researchers and users of the coastal marine domain, create product prototypes for EU marine core services and users of the coastal domain, support excellence in marine coastal research to better answer societal and policy needs.	observatories: Integration of (existing) infrastructures and of access to data and tools – Expertise and development of best practices (instrument application, quality assessment, etc.) in six observing systems: gliders, fixed platforms, ferry boxes, HF radars, bottom-based observatories, coastal profilers, and related data flows – Promoting the measurement of a shared list of priority variables at all observatories addressing the needs of environmental monitoring, Regional Sea Conventions, the European Water Framework and Marine Strategy Framework Directives
SeaDataNet	H	Management of oceanographic data (physical, chemical, geological, biological) and its steadily improvement	– Providing timely and high-quality access to a broad spectrum of marine metadata, data and data products (with focus on in situ data) – Defining, adopting and promoting common data management standards and realizing technical and semantic interoperability with other relevant data management systems and initiatives to serve science, environmental management, policy-making, and the economy
SIOS	A, H	Build a regional observational system for long-term acquisition and proliferation of fundamental knowledge on global environmental change within an Earth System Science perspective in and around Svalbard.	– Integration with other domains for coherent and comprehensive research in the Svalbard region, answering key questions in Earth System Science (especially Arctic amplification, Arctic water cycle, anthropogenic forcing), focus on Svalbard land mass and biota interactions with changing climate; specific interest in variables that link the different domains to each other, e.g. GHG fluxes or snow properties – Offering access to various infrastructures in Svalbard and harvest/ assemble Svalbard-specific data, coordinating the long-term monitoring (participating stations can have additional campaigns) – Develop and implement new methods for how observational networks are to be developed in the Arctic and Polar regions. – Grand Challenge Initiative Cusp rocket campaigns to answer questions related to the energy transport through the polar atmosphere (complement the vertical coverage of observations)

The compilation shows clearly the challenge of a multi-dimensional system of competences. Each RI has ***technological competences*** but these cover a wide range from observation systems with specific scientific scope (e.g. ICOS) and technology-specific observational platforms (e.g. EUFAR) via experimental facilities (e.g. AnaEE and Aquacosm) and modelling platforms with specific model competences (e.g. IS-ENES) to pure e-infrastructures (e.g. LifeWatch and SeaDataNet). Most of the RIs have furthermore a more or less ***specific scientific scope*** and are answering specific ***Grand Challenges*** through the provision of ***Essential Variables***. Another dimension is the ***geographical coverage***. Some RIs (e.g. SIOS) have a very clear geographical focus while many others aim to cover the whole continent. This first approach needs to be deepened to enable the ESFRI to monitor the development of the landscape and to steer future collaboration strategies.

3 Description of current and potential future collaborations

The ENVRI community has provided the ENVRI sustainability plan (ENVRIPLUS Deliverable 17.5) and ENVRI strategy (ENVRIPLUS Deliverable 17.2). Both documents were discussed in the BEERi, where a common direction of the ENVRI cluster towards a consortium agreement and a coordinated funding and communication strategy was agreed and started. This document – together with deliverable 12.3 – also supports the further development of the domain and as such builds a triangle of viewpoints towards future collaboration among the ENVRIs.

The current situation is not void of any cooperation between the RIs. A lot of collaboration topics are already addressed. Particularly, when it comes to common approaches in data handling, the impact of the ENVRI and ENVRIPLUS projects is high and will be deepened in the ENVRI-FAIR project. Further collaborations will be briefly described in the following paragraphs. They document current efforts that guide towards even better collaboration and enhanced efficiency. For each sector of collaboration identified below, a description of the existing situation will be complemented by possible activities towards enhanced cooperation and better integration. Not all the sectors are applicable to all RIs.

3.1 Utilisation and strengthening of complementarities

3.1.1 Sharpening of core competences for cross-RI services

Based on sharp descriptions of scientific, methodological and technical core competences of each of the single RIs, models of RI to RI services can be developed. If one RI has e.g. developed a world-leading position in the processing and quality assurance of data from a specific instrument or methodology, other RIs should use this instead of wasting resources by building parallel redundant competences. A cross-RI system of services would unlock enormous resources.

3.1.2 Securing and extending the coverage of Essential Variables (EVs)

The ENVRI community as an ensemble of RIs covers a lot of EVs in the UNFCCC (GCOS) as well as the UNCBD (GEOBON) systems. However, the ensemble is yet not very well concerted. The ENVRI community should take this topic up and strengthen a strategic approach to develop joint contributions and clear common data streams towards EVs. Some RIs with already built up competences in that field may service the community here as well. A first overview for the atmosphere and the hydrosphere domains, respectively, are given in the Appendices.

3.2 Multi-platform observing system design and implementation

Site co-location is one of the most direct ways to collaborate. Data interoperability is very beneficial at co-located research sites, as it allows, e.g., for common data streams to data repositories. The inventories of

site locations of RIs in the atmosphere and hydrosphere domains, which are presented in Appendices 1 and 2, show that the total coverage of RIs is excellent, even if most of them do not individually cover the whole European area, let alone the globe. Further work is needed to identify in detail where a specific RI could benefit from the location of an existing station of another RI. Even more interesting, and demanding even further work, would be to identify new locations that would be interesting for more than one RI and to plan the installation of a combined measurement facility that would serve the needs of several RIs. This is particularly true for RIs of the same domain (e.g. atmosphere) where similar technologies can serve multiple purposes. The benefits would at least be based on the common use of the infrastructure and logistics available (electricity supply, data collection…). Further integration at co-located sites would greatly improve transdisciplinarity among RIs.

3.3 Integration into regional and global programs and initiatives

As key elements of the European Research Area (ERA), ENVRI research infrastructures need to be strongly integrated into larger frameworks to fulfil their potential. If the natural playground is Europe, other regional and global initiatives are essential to ensure the relevance, visibility and impact of RIs. This is especially true for environmental infrastructures as the challenges they need to address are most often of a global nature.

If each domain has a portfolio of specific frameworks at their disposition, the major regional global actors can welcome the contributions of RIs across domains. This is for instance the case of the World Meteorological Organization (WMO) that provides, through different programs, a space for cooperation. Several RIs operate World Calibration or Data Centers (WCCs or WDCs) or develop joint standards and protocols for the Global Atmosphere Watch (GAW) program.

Observational RIs are also important in situ data sources for the European Union's Earth observation program Copernicus, which offers information services based on satellite Earth observation, in situ data (ground-based, sea-borne or air-borne monitoring systems, as well as geospatial reference or ancillary data) and modelling. Several RIs contribute to the activities of some of the six Copernicus services, like the Copernicus Atmosphere Monitoring Service (CAMS), the Copernicus Marine Environment Monitoring Service (CMEMS)or the Copernicus Climate Change Service (C3S).

Another area of cooperation between the RIs in ENVRI and Copernicus are the Data and Information Access Services (DIAS). They are a set of cloud-based platforms with central access to Copernicus data and information. Direct data flow from the RIs to DIAS is foreseen but not operational yet.

For the contributions of RIs to projects and databases, more information is available in the domain reports (Appendices 1 and 2)

Framework	Contributing RIs
WMO	ICOS (collaborating network of GAW; TCCON, which is planned to integrate into ICOS in Europe, is also a contributing member of GAW; contribution to IG^{3}IS; participation in international inter-comparison programs to assure the data compatibility with the other international networks such as GAW)
WMO (cont.)	ACTRIS (collaborating network of GAW for observations; operation of WCCs and WDCs, development of standards and protocols)

	ARISE (co-location of lidar station with GAW station Hohenpeißenberg (Germany); Maïdo lidar station at Reunion Island (France) is candidate for GAW station) EUFAR (development of GAW standards and protocols; recommendation of WMO standards and guidelines to TNA users) IAGOS (collaborating network of GAW; joint development of standards and protocols; operation of Quality Assurance/ Science Activity Centre, Central Calibration Laboratory) EUROCHAMP (operation of WCC) IS-ENES (use of GAW data in global atmospheric models) SIOS (provision of some stations data to GAW)
COPERNICUS	ICOS (provision of NRT data; validation of regional and global models and CAMS forecast products; in the future, provision of TCCON data would be beneficial to CAMS; provision of data to CMEMS) ACTRIS (provision of RT and NRT atmospheric profiles of ozone and aerosol properties; validation of regional and global models) IAGOS (NRT monitoring of global atmospheric composition; provision of data and tools for validation of CAMS reanalysis; validation of regional and global models) IS-ENES (support of the data base for climate projections brokered by C3S) EMSO (provision of data to CMEMS via OceanSITES) Euro-ARGO (provision of raw and reprocessed data to CMEMS, for assimilation in models and reanalysis) EUROFLEETS (provision of data to CMEMS from vessels through National Oceanographic Data Centres (NODCs)) EuroGOOS (facilitation of CMEMS INSTAC) JERICO (provision of data to CMEMS; interaction planned with C3S and Copernicus Land Monitoring Service (CLMS) to complement existing activities with CMEMS) SeaDataNet (quality control of data from CMEMS INSTAC; provision of long-term archives and data management standards)

The active participation of some RIs in global policy-making frameworks represents another level of cooperation. The different UN conventions that govern the environmental activities (UNFCCC for climate change, UNCDB for biodiversity, Sendai Framework for Disaster Risk Reduction…) offer a platform to advance the work and impact of RIs. Currently, only ICOS has completed the formal procedure to become a member organization of UNFCCC. Its membership was accepted in 2019. For RIs of the hydrosphere domain, the UN Decade of Ocean Science for Sustainable Development that will be launched in 2021 will certainly increase the momentum around their activities. Another important global framework for the environmental RIs is the Global Carbon Observing System (GCOS). As a joint program of the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission of UNESCO (IOC-

UNESCO), the United Nations Environment Programme (UN Environment), and the International Science Council (ISC), GCOS plays a major role in defining the scope of activities for observational networks throughout the world. By maintaining the system of Essential Climate Variables (ECVs), it helps identify gaps in systematic observation. and contributes to the alignment of the measurements made around the globe.

The environmental RIs are made of a vast community of scientists, experts in all disciplines related to Earth sciences. A significant number of them contribute to the work of the Intergovernmental Panel on Climate Change (IPCC), especially to the assessment reports that are published on a regular basis as well as the topical reports (SR15 on 1.5 ºC, SRCCL on Climate Change and Land…). The contribution of the ENVRI community also goes to other actions of IPCC. The recently published 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories contains a new section on "Comparison of greenhouse gas emission estimates with atmospheric measurements". This is potentially a game-changer for the environmental RIs of the atmospheric domain as it means their data will be used much more extensively in the future for the reporting of emissions by countries. A larger focus on the role of atmospheric measurements is to be expected by many countries that will want to improve their reporting practices. The long-term advocacy of the scientific community resulted in Chapter 6.10.2 of Volume 1 "Comparisons with atmospheric measurements" of the Refinements that will open for enhanced cooperation between the RIs and the inventory community.

The Group on Earth Observations (GEO) remains a relevant intergovernmental framework for many RIs of the ENVRI community. Guided by its three-year Work Programs (the next one being 2020–2022), the activities in GEO are structured around initiatives where e.g. EPOS and ICOS are participating organizations.

Just as for the Global Atmosphere Watch (GAW) of WMO in the case of atmospheric RIs and their data, the Surface Ocean CO_2 Atlas (SOCAT) is a synthesis activity for quality-controlled, surface ocean fCO_2 (fugacity of carbon dioxide) observations provided by the international marine carbon research community. The annual releases of SOCAT data ensure a large visibility of the work performed by the RIs of the hydrosphere domain and the best use of their data.

3.4 Joint fit-for-purpose services and products

The domain reports for atmosphere and hydrosphere presented in Appendices 1 and 2 have started to collect an inventory of the products and services developed by each RI, beyond the "simple" provision of observation data. This inventory needs to be continued and complemented by an evaluation of areas where common products and services could be proposed.

The connections of the RIs to the regional and global actors mentioned above is already used to make use of data from different RIs for joint products. This is e.g. the case in the hydrosphere domain with CMEMS

Several of these domains can be listed already, although little development has started yet among the RIs. Indeed, if it would be advisable that each RI does not develop a service or product isolated from the other RIs, it is in practice difficult to overcome the challenges of RIs having different maturity levels, different target communities, etc. The topics for common activities could be:

- training (on organizational aspects specific to distributed RIs, big data management…),
- use of shared catalogues (for site, data and service description),
- development of Virtual Research Environments (VREs),
- shared data centers,
- common validation and calibration services for remote-sensing instruments,
- more generally, development of services to address the needs of common users like the Global Carbon Project.

3.5 Joint technological developments and industrial innovation

Collaborations among each other and with the industry are becoming increasingly important for the RIs in order to foster technological developments (e.g., instrumentation) and innovations, which are, however, not in the focus of all RIs.

The specific technological requirements attached to each RI make it difficult to envisage common industrial collaborations but it is not excluded that some fields are possible. This is for instance the case for EMSO and ICOS that are both interested in measuring pCO_2 in the ocean or IAGOS and ACTRIS that study reactive gases like ozone in the atmosphere.

The ENVRI community has started a fruitful dialogue with the industrial world through the 1st EU Environmental Research Infrastructures–Industry Joint Innovation Partnering Forum organized in 2017 in Grenoble. This event brought together more than twenty companies and the representatives of all environmental RIs. A combination of scientific and technical presentations made it possible to open new cooperation channels.

3.6 Common engagement activities of user communities

The engagement of user communities, be they scientists, information services such as Copernicus, or the industry, is crucial for the impact of RIs. Once these communities have been identified as target stakeholders of the RIs, they need to be included in engagement activities that provide them with information or services that meet their needs.

Considering the structure of most RIs (e.g. as organizations having European Member States as shareholders), it is obvious that some of the stakeholders are, if not identical, at least similar in terms of expectations and needs. The same applies to the users of data who, although active in different scientific domains, are very comparable and have at their disposal similar communication channels. It is advisable that, at least, the best practices in terms of user engagement strategies are shared between the RIs of the environmental domain. Even better would be a collective reflection on major user groups that could then be targeted with common engagement tools and practices.

3.7 Collaboration towards structural integration

It is currently not envisaged to merge RIs or to otherwise integrate the landscape structurally. Notwithstanding this remains a possibility for which the ENVRI community should prepare. It includes a broad spectrum of measures:

- RI to RI services could sharpen the technical or scientific profiles of the along the core competences of the RIs and avoid parallel developments.
- Common facilities could be developed between two or even more RIs.
- Joint memberships could make a group of RIs attractive to many countries and reduce the competition for member countries.

Details about collaboration at the domain level can be obtained from the respective reports.

Appendix 1: Landscape of European ENVRIs in the atmospheric domain and suggestions to foster collaborations

Leading beneficiary: ICOS ERIC

Version: 2.0

Date	Authors, RI	Version
20190403	Daniela Franz, ICOS ERIC	Initial draft, for comments
20190426	Daniela Franz, ICOS ERIC Emmanuel Salmon, ICOS ERIC Sanna Sorvari Sundet, ACTRIS Niku Kivekäs, ACTRIS Elisabeth Blanc, ARISE Anders Tjulin, EISCAT-3D Phil Brown, EUFAR Andreea Calcan, EUFAR Matilde Oliveri, EUROCHAMP Jean-Francois Doussin, EUROCHAMP Felix Friedl-Vallon, HEMERA Andreas Petzold, IAGOS Valerie Thouret, IAGOS, Alex Vermeulen, ICOS ERIC Leonard Rivier, ICOS ERIC Sylvie Joussaume, IS-ENES Heikki Lihavainen, SIOS	Commented and revised

Abstract

This study represents an analysis of the current landscape of European environmental research infrastructures (RIs) in the atmospheric domain. The landscape is described from different perspectives, focusing on the relation of the RIs to Grand Challenges, their core competences and how they cover Essential Variables in atmospheric research, as well as complementarities and collaborations. The analysis further comprises information on the scientific background of the RIs, the integration of the RIs into regional and global frameworks, complementarities and collaborations, user communities, services and products, station/ facility locations as well as data interoperability.

Ten RIs are considered in the analysis (ACTRIS, ARISE, EISCAT_3D, EUFAR, EUROCHAMP, HEMERA, IAGOS, ICOS, IS-ENES, SIOS), differing in their maturity, sustainability and methods ranging from long-term atmospheric observation platforms and one network of experimental platforms to model development and numerical experiments. Some RIs are restricted to the atmospheric domain, while others cover multiple domains in the environmental field.

The analysis aims to provide a clear view on the landscape and is of particular interest to foster a more efficient and comprehensive collaboration between the RIs and to support future strategic planning within the domain. The study will help to identify potential next steps in the collaboration towards an integrated observing system and to develop ideas for joint products and services following joint long-term research topics. The report will provide the domain-specific input for a white paper integrating all domains of the environmental field.

Background and motivation

The European culture of cooperation and inclusiveness is exceptional compared to other regions of the world, where research is more competitive and less open science focused, and is strongly supported by common legal frameworks, which facilitate efficient governance and research funding. Research Infrastructures represent major elements of the competitiveness of the European Research Area (ERA). Intense collaboration between RIs is expected by the European funding agencies in order to optimise the landscape and strengthen the excellence and impact of European research.

The projects ENVRI (2011-2014, FP7-INFRASTRUCTURES-2011-1 – ID 283465) and ENVRIPLUS (2015-2019, H2020 INFRADEV-4-2014-2015 – ID 654182) have largely contributed to structure the complex landscape of Environmental and Earth System Research Infrastructures (ENVRI) in Europe and to join forces to tackle common challenges. ENVRIPLUS is bringing together research infrastructures (RIs), projects and networks as well as technical specialist partners to create a more coherent, interdisciplinary and interoperable cluster of Environmental Research Infrastructures across Europe, continuing and deepening the work done in the ENVRI project. The Board of European Environmental Research Infrastructures (BEERi) established under ENVRIPLUS is a major forum for the cooperative work between RIs.

ENVRIPLUS Deliverable 12.3 (Kutsch et al., 2017) made an important contribution towards a beneficial cooperation between European environmental research infrastructures (RIs) in the Terrestrial Ecosystem Domain. At its Zandvoort meeting (May 2018), the BEERi decided to produce a similar deliverable for the atmosphere and marine domains. The Executive Board of ENVRIPLUS assigned this duty to Task 17.1 (*Facilitation of the communication and coordination at the domain level on the ENVRI strategy*), Deliverable 17.6 (*White paper on further integration of RIs in the environmental field including recommendations on co-locating research sites on national and international level*).

The activities on this deliverable started in August 2018. Based on initial interviews with key persons of the RIs (see Appendix A – List of interview partners), the contents and expected outputs of the analysis were

discussed during the ENVRI week in Riga (November 2018) and in a related BEERi strategy workshop. A concrete concept was developed and discussed in the BEERi meeting in Prague (January 2019).

The goal of Deliverable 17.6 is to foster a comprehensive and efficient cooperation between the RIs by providing a clear view on the current ENVRI landscape (and particularly, who is doing what and which niche each RI is occupying) and identifying potential joint long-term research topics as well as products and services. The deliverable will pave the way to address the Grand Challenges jointly, and thus more effectively, and will support the evolution of the RIs towards more service-oriented organisations, which produce synthetic knowledge services. The expected outputs are single domain reports for the atmosphere and marine domains and a final integrating white paper across domains of the environmental field, including Deliverable 12.3. The activities in Deliverable 17.6 are complementing the discussion on the future structural mode of the ENVRI community within D17.5.

Scope of this report

This study aims to describe the current landscape of the European environmental RIs in the atmospheric domain from different perspectives, and to analyse existing and develop new links between the RIs. The report will support the future strategic planning within the domain and can feed the discussion process among the involved RIs, user communities and stakeholders from national governments on the potentials for further collaboration between the RIs towards an integrated European observation system. Furthermore, this can help the RIs to respond jointly on upcoming calls in the next research funding programme of the EU. The report is planned to be utilized as an input to work package 8 of the ENVRI-FAIR H2020 project (2019-2022, H2020-INFRAEOSC-2018-2020 - ID 824068). For this purpose, the description of complementarities and the coverage of core variables as well as an initial inventory of the products and services provided by the RIs are of particular importance. Based on this information, ideas for joint products and services following joint long-term research topics can be developed. The report will provide the domain-specific input for the white paper integrating all domains of the environmental field, which will (as part of the updated ENVRI strategy) be proposed to the European Strategy Forum on Research Infrastructures (ESFRI;[1]) for consideration during the process of developing the ESFRI Roadmap 2021. The landscape is presented mainly with a narrative approach, as graphical representations fail to represent the landscape appropriately.

Research infrastructures included in the analysis

For the purpose of clarity, we split the ENVRI cluster into different domains, but we are fully aware that there are manifold interrelations between the domains, which are important to be considered. Alternative approaches to describe the landscape include the cycle approach (e.g., carbon cycle, nitrogen cycle), which, however, might not be appropriate for the ENVRI cluster yet.

This landscape analysis involves all transnational European RIs of the atmospheric domain (ACTRIS, IAGOS, EISCAT_3D) and multi-domain RIs covering the atmospheric domain (ICOS, SIOS, IS-ENES) (referred to as 'RIs in the atmospheric domain' in the following) which are directly participating in ENVRIPLUS, as well as ENVRIPLUS associated RIs (ARISE, EUFAR, EUROCHAMP, HEMERA), see

[1] ESFRI is a strategic instrument to develop the scientific integration of Europe and to strengthen its international outreach.

Table 1. Thereby, it focusses on RIs identified by ESFRI Strategy Working Group on Environment as long-term 'research facilities of pan-European importance that are necessary to strengthen scientific excellence and competitiveness in the EU (ESFRI Roadmap 2018), but is not restricted to those. The analysis needs to reflect the broader landscape (beyond the ESFRI roadmap) in order to support further cooperation and integration, as there are several reasons for RIs to be missing on the ESFRI roadmap. For instance, the RI is still in the process of building a tighter scientific community, funded by the European Commission as Integrating Activity or at the beginning of the preparation phase as Design Study (for the development of a new pan-European RI) and has not reached the maturity to be listed. Or, the RI is lacking the pan-European dimension that is required for ESFRI Landmarks, national roadmap processes and missing political/ financial commitments to enter the ESFRI process (RI is trapped in an eternal project cycle) or non-recognition of specific legal entities.

TABLE 1: OVERVIEW ON RIS INVOLVED IN THIS ANALYSIS, REPRESENTING DIFFERENT MATURITY LEVELS. ESFRI PROJECTS ARE RIS IN THEIR PREPARATION PHASE, WHEREAS ESFRI LANDMARKS ARE RIS THAT WERE IMPLEMENTED OR REACHED AN ADVANCED IMPLEMENTATION PHASE UNDER THE ROADMAP AND THAT REPRESENT MAJOR ELEMENTS OF THE COMPETITIVENESS OF THE EUROPEAN RESEARCH AREA. SINGLE-SITED RIS ARE CENTRAL FACILITIES GEOGRAPHICALLY LOCALISED AT A SINGLE SITE OR AT A FEW DEDICATED COMPLEMENTARY SITES DESIGNED FOR USER ACCESS, WHOSE GOVERNANCE IS EUROPEAN OR INTERNATIONAL, WHEREAS DISTRIBUTED RIS CONSIST OF A CENTRAL HUB AND INTERLINKED NATIONAL NODES (ESFRI ROADMAP 2018). ERIC IS THE LEGAL FRAMEWORK FOR A 'EUROPEAN RESEARCH INFRASTRUCTURE CONSORTIUM' TO SUPPORT THE IMPLEMENTATION OF PAN-EUROPEAN RIS. AISBL IS AN INTERNATIONAL NON-PROFIT ASSOCIATION UNDER THE BELGIAN LAW.

RI	Status in ESFRI	Status of development/ legal status	RI type	Focus	Website
ESFRI Landmarks					
EISCAT_3D (European Incoherent Scatter Scientific Association – 3D)	ESFRI Landmark (roadmap entry 2008), in Implementation/ Construction Phase	integral part of EISCAT Scientific Association (non-profit organisation in Sweden since 1975); Implementation (Preparation for production); planning to be operational in 2022	- Single-sited - Long-term atmospheric observation platform	Coupling of Earth´s polar atmosphere to space (particularly space weather)	www.eiscat.se/blog /category/eiscat3d/
IAGOS (In-Service Aircraft for a Global Observing System)	ESFRI Landmark (roadmap entry 2006)	AISBL (since 2014), operational since 2014	- Distributed - Long-term atmospheric observation platform	Atmospheric composition in the lower atmosphere (0-12 km)	www.iagos.org/
ICOS (Integrated Carbon Observation System)	ESFRI Landmark (roadmap entry 2006)	ERIC (since 2015), planning to be fully operational in 2019; associated Implementation project: Readiness of ICOS for Necessities of integrated Global Observations (RINGO[2])	- Distributed - Multi-domain (Atmosphere, Terrestrial Ecosystem and Marine Domains)	Carbon cycle and greenhouse gases	www.icos-ri.eu/

[2] www.icos-ri.eu/ringo

RI	Status in ESFRI	Status of development/ legal status	RI type	Focus	Website
			- Long-term atmospheric observation platform		
ESFRI Projects					
ACTRIS (Aerosol, Clouds and Trace Gases Research Infrastructure)	ESFRI Project (roadmap entry 2016)	H2020 projects: ACTRIS-2 (Integrating Activity, 2015-2019) and ACTRIS PPP (Preparatory Phase Project, 2017-2019); has submitted ERIC step 1 proposal in 2019; planning to be operational in 2025	- Distributed - Long-term atmospheric observation platform & Exploratory process-oriented research	Aerosols, clouds and trace gases	www.actris.eu/
Other RIs (communities, projects)					
ARISE (Atmospheric Dynamics Research InfraStructure in Europe)	(mentioned in ESFRI Roadmap Landscape analysis)	ARISE2 as H2020 Design Study project until 2018; ARISE3 project planned	- Distributed - Long-term atmospheric observation platform - Multi-disciplinary	Atmospheric dynamics	http://arise-project.eu/
EUFAR (European fleet for airborne research)	(mentioned in ESFRI Roadmap Landscape analysis)	AISBL (since 2018)	- Distributed - Multi-domain (Atmosphere, Terrestrial Ecosystem and Marine Domains) - Exploratory process-oriented research	(Access to) Instrumented aircrafts and hyperspectral imaging sensors	www.eufar.net/

RI	Status in ESFRI	Status of development/ legal status	RI type	Focus	Website
EUROCHAMP	(mentioned in ESFRI Roadmap Landscape analysis)	EUROCHAMP-2020 as H2020 project (Integrating Activity, 2016-2020)	- Distributed - Exploratory process-oriented research	(Access to) Atmospheric simulation chambers	www.eurochamp.org/
HEMERA	-	H2020 project (Integrating Activity, 2018-2021)	- Distributed - Exploratory process-oriented research	(Access to) Balloon-borne platforms (stratosphere, troposphere)	www.hemera-h2020.eu/
IS-ENES (Infrastructure for the European Network for Earth System Modelling, ENES)	(mentioned in ESFRI Roadmap Landscape analysis)	IS-ENES3 as H2020 project (2019-2022)	- Virtual (e-infrastructure) - Multi-domain (focus on atmospheric domain) - Modelling development and experiments	(Access to) reference simulation data from global and regional climate and Earth system models	https://is.enes.org/
SIOS (Svalbard Integrated Arctic Earth Observing System)	(mentioned in ESFRI Roadmap Landscape analysis; was on roadmap 2008-2018)	Norwegian public (non-profit) limited company	- Distributed - Multi-domain (Atmosphere, Terrestrial Ecosystem and Marine Domains) - Long-term atmospheric observation platform	Integrating biosphere, cryosphere, terrestrial, marine and atmospheric observations at Svalbard	https://sios-svalbard.org/

The landscape analysis will be updated regularly as the landscape is expected to change continuously especially due to the formation of new RIs, but probably also due to consolidation processes. In addition, other research communities might be integrated into existing RIs, as one solution for project-based networks facing the challenge of sustainability. One example is the considered integration of the European pillars of the Total Carbon Column Observing Network (TCCON[3]) and AirCore[4] into ICOS, and the co-location with atmospheric stations in order to foster the interoperability with satellite data as a prerequisite for the integration of ICOS into a global observational system.

The landscape in the atmosphere domain appears well structured, with a clear task distribution among the RIs that are complementing each other. RIs in the atmospheric domain are diverse, e.g., related to the scientific background, maturity, sustainability and in the methods. Furthermore, RIs producing measurement data further differ with regard to, e.g., the observation frequencies, the quality of the measurements and how they acknowledge uncertainties. The specific role of the RIs contributing to the atmospheric domain is to provide data and services which are crucial for research on and the understanding of atmospheric chemistry, physics and dynamics, as well as the interaction with terrestrial ecosystems, the marine, solid earth systems and the near space. The portfolio of RIs considered in this analysis comprises long-term atmospheric observation platforms (EISCAT_3D, IAGOS, ICOS, ACTRIS, ARISE, SIOS), as well as networks of experimental platforms, offering physical access and facilitating exploratory process-oriented research (EUFAR, HEMERA and EUROCHAMP) and one RI focusing on model development and numerical experiments (IS-ENES). RIs in the first group coordinate observations which are targeting specific scientific questions (science-driven), and provide their user groups with free and open access to, e.g., high-quality observational data, either long-term or campaign-based, as well as tools for quality assurance and various data products. Experimental platforms are accessible for a broader community to address diverse research questions (user-driven). Whereas the roles of EUFAR and HEMERA are focused on the provision of the technological capabilities for the scientific user communities, activities within EUROCHAMP exceed basic services provision towards the preparation of the facilities to access emerging environmental issues. However, in case of EUFAR, some of the partner organisations are involved as both the facility operator/ provider and as part of the wider scientific user community within their country. IS-ENES provides access to common climate model software and to model data from the World Climate Research Programme (WCRP[5]) coordinated simulations extensively used as a reference for IPCC and climate studies

Atmospheric observations inherently do not reflect the conditions of certain spatially restricted areas. For instance, GHGs and aerosols may be transported from emission to receptor sites over long distances in the atmosphere, crossing borders, continents and oceans. Nevertheless, differences exist of course in the geographical target area of the RIs. Whereas SIOS is regionally focused on the Norwegian archipelago of

[3] TCCON is a global network of ground-based Fourier Transform Spectrometers recording direct solar spectra in the near-infrared spectral region, being complementary to in situ measurements and of strong importance for the validation of satellite data, i.e. to detect and quantify spatial biases and/ or temporal shifts in satellite retrievals (e.g., ENVISAT, GOSAT, OCO-2). The network exists since 2004 and is in transition from a research network to a monitoring network, however, currently it receives its funding from short-term projects and institutions and is dedicated to research rather than long-term monitoring. TCCON measurements themselves have to be indirectly calibrated by airborne measurements, e.g., with AirCore or other in situ observations. Task 3.1 of the H2020 project RINGO aims to develop the readiness of in situ vertical profile measurements using AirCore at ICOS stations and vertical TCCON profile measurements of CH_4. www.tccon.caltech.edu/

[4] AirCore is an atmospheric sampling system that consists of a long tubing, that samples the surrounding atmosphere and preserves a profile of trace gases from the middle stratosphere to the ground.

[5] www.wcrp-climate.org/

Svalbard, IAGOS and IS-ENES are targeting the global scale. Observations provided by the RIs cover the full altitude range of the atmosphere from the ground to the ionosphere.

RIs in the atmospheric domain evolved primarily from established communities focusing on specific (observational) methods or atmospheric variables. Apart from improvements in the efficiency, the consolidation processes that took place allowed to reach a critical mass in order to constitute a RI. The most prominent examples for the integration of several communities are ACTRIS and ARISE. ACTRIS assembles CREATE[6]/ EUSAAR[7]/ ACTRIS-IA, EARLINET[8], the short-lived components of NDACC[9], AERONET[10], CLOUDNET[11] and EUROCHAMP. ARISE includes the European parts of the International Monitoring System (IMS) infrasound network[12] developed to ensure compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT[13]), complementary infrasound stations, NDACC lidar stations, as well as stations and station networks with other technologies. The latter include, for instance, an observatory using the microwave technique (Maïdo Observatory on Reunion Island), airglow observatories (NDMC[14]), the Andøya Space Center observatory (ALOMAR), and complementary radars and ionospheric sounding systems.

Experimental platforms are building predominantly on the technological capabilities and are designed for interdisciplinary and cross-domain research. They could therefore be considered as multi-domain RIs. Apart from observations of the atmosphere (including dynamics, composition, aerosols and clouds, and radiation transport), EUFAR facilities, for example, further facilitate remote sensing of land/water surfaces for a wide range of applications (including land-surface interactions with the atmosphere, vegetation, soil-moisture and minerals). Balloon flights provided by HEMERA can, e.g., be used to measure sounds from the earth´s crust (Krishnamoorthy et al., 2018).

ACTRIS has a big community, accelerating processes towards an ERIC by a combination of two H2020 projects (Integrating Activity and Preparatory Phase Project). ACTRIS is dedicated to observations of aerosols, clouds and short-lived gases, and includes ground-based stations providing long-term observations, experimental platforms, instrument calibration centres and a data centre.

ARISE is currently preparing a proposal for a H2020 Integrating Activity (ARISE IA) with focus on the dynamics of the Middle Atmosphere, in broad time and space scales, and model assessment with extension of the multidisciplinary observation network, improvement (e.g., in terms of interoperability) of the ARISE data portal, which is a demonstrator developed in the framework of the ARISE2 Design Study, as well as on the continuation of prototype development and the transfer of prototypes to operational products.

EISCAT_3D is currently in the Implementation/ Construction Phase, building up a next-generation Incoherent Scatter Radar (ISR) system (distributed phased array radars) as an upgrade of the EISCAT[15] system. It enables three-dimensional observations of ionospheric parameters and atmospheric dynamics

[6] Construction, use and delivery of an European aerosol database, https://cordis.europa.eu/project/rcn/69064/factsheet/en
[7] European Supersites for Atmospheric Aerosol Research, www.eusaar.net/
[8] European Aerosol Research Lidar Network, www.earlinet.org/index.php?id=earlinet_homepage
[9] Network for the Detection of Atmospheric Composition Change, www.ndacc.org/
[10] Aerosol Robotic Network, https://aeronet.gsfc.nasa.gov/
[11] www.cloud-net.org/
[12] www.ctbto.org/verification-regime/monitoring-technologies-how-they-work/infrasound-monitoring/
[13] www.un.org/disarmament/wmd/nuclear/ctbt/
[14] Network for the Detection of Mesopause Change, https://ndmc.dlr.de/sites/wdc.dlr.de.ndmc/files/documents/ndmc_poster_dinA0_6apr.pdf
[15] www.eiscat.se/

above Northern Fenno-Scandinavia, which is an important location for research on coupling between space and the polar atmosphere.

EUFAR offers researchers open access to airborne facilities, representing all-purpose platforms, facilitating a diverse portfolio of observations. Following four EU projects since 2000 with changing consortia, it was transformed into an AISBL in 2018, facilitating its sustainability. The extension of the consortium is desired.

The **EUROCHAMP** community is currently running an Integrating Activity project, aiming to further integrate the most advanced European atmospheric simulation chambers. The project follows two previous EU projects of the community. A clear convergence is established between ACTRIS and EUROCHAMP communities to merge activities into ACTRIS at the end of the two current EU Integrating Activity projects. The simulation chamber data will be one pillar of the ACTRIS data centre.

In 2018 **HEMERA** appeared in the landscape as a 4-year H2020 project with partners from space agencies and space access providers as well as scientific bodies and industry. It integrates the community in the field of tropospheric and stratospheric balloon-borne research, to make existing balloon facilities available to scientific teams in the European Union, Canada and associated countries. The project was set up in the light of decreasing national (e.g., in France, Sweden) and increasing international demand. As typically for a project-based network of experimental platforms, it has three major elements, including Transnational Access (TNA) to balloon flights, Networking (to strengthen and enlarge the user community) and Joint Research Activities (JRAs), to improve ballooning technology and scientific instrumentation). The actual demand and scientific output of HEMERA has to be evaluated at the end of the project in 2021.

IAGOS is an established RI in the landscape, conducting long-term observations of atmospheric composition, aerosol and cloud particles on a quasi-global scale by deploying autonomous instruments aboard a fleet of commercial passenger aircrafts. It combines the expertise of the two former European research projects MOZAIC[16] and CARIBIC[17]. Data are used for model and satellite validations as well as for the characterisation and investigation of leading processes for mean distributions, variabilities and trends of climate and air quality relevant variables.

ICOS provides long-term observations required to understand the present state and predict the future behaviour of the global carbon cycle and greenhouse gas emissions and concentrations. As one of the few multi-domain RIs, ICOS integrates atmosphere, terrestrial ecosystem and ocean greenhouse gas observations. ICOS has a large community in all three domains and currently has planned 34 atmospheric stations out of more than 130 ICOS stations in total in the 12 member states. The atmosphere stations continuously measure GHG concentrations of CO_2, CH_4, CO and ancillary tracers like ^{222}Rn and $^{14}CO_2$ in the atmosphere to quantify the fossil fuel component. The measurements are used to validate and reduce uncertainties in climate models and feed inversion or assimilation data fusion systems to produce regional and global GHG budgets. The H2020 project RINGO fosters the scientific, geographical, technological, data-related as well as policy-related and administrative readiness of ICOS.

IS-ENES, as the infrastructure on models, model data and metadata of the European Network for Earth System Modelling (ENES), is the only completely virtual infrastructure (e-infrastructure) in the landscape of atmospheric RIs. In January 2019, IS-ENES launched its next H2020 project (IS-ENES3), continuing the joint work of seven European modelling groups to understand and predict climate variability and change

[16] Measurement of Ozone and Water Vapour on Airbus in-service Aircraft, see www.fz-juelich.de/SharedDocs/Downloads/IEK/IEK-8/EN/terminatedProjects/MOZAIC.pdf?__blob=publicationFile

[17] Civil Aircraft for the Regular Investigation of the atmosphere Based on an Instrument Container, see www.caribic-atmospheric.com/Home.php

(climate modelling centres or met offices in France, Germany, Italy, Norway, Spain, Sweden and UK). The focus of the third phase mainly lies on the contributions of IS-ENES to the Coupled Model Intercomparison Project Phase 6 of the World Climate Research Programme (CMIP6[18]) and the dissemination of software, as well as on further establishing the IS-ENES as RI (as an agreement between countries rather than through the ESFRI process, which might be targeted later).

SIOS constitutes an exception with regard to the geographical coverage as a regional observing system. It coordinates and integrates long-term measurements in and around the Norwegian archipelago of Svalbard and addresses a broad variety of Earth System Science questions.

A. Landscape of environmental research infrastructures in the atmospheric domain

A.1 Scientific background and relation to Grand Challenges

One option to describe the landscape of RIs in the atmospheric domain is according to the scientific questions they address. Environmental research is key to understand the Earth system and its functioning in order to reduce environmental risks. Environmental RIs are of high importance for both fundamental and applied research. Nowadays, the European Union orients its scientific funding programme particularly to Grand Challenges, i.e., research should be driven by the needs of society and economy. Thereby, it supports RIs as 'facilities, resources and services used by the science community to conduct research and foster innovation' and as key elements of the European Research Area. Environmental RIs are linked to several frameworks addressing Grand Challenges for society and economy, including the UN Agenda 2030 which is anchored by Sustainable Development Goals (SDGs), covering a broad range of challenges, and some more specific frameworks such as the Paris Agreement (climate change, related to SDG13), Rio Convention on Biodiversity (loss of biodiversity, related to SDGs 14 and 15) and the Sendai Framework (disasters, related to SDG11).

The SDG system has 17 targets, whose progress is evaluated based on several specific indicators for each target. Environmental RIs mainly contribute to the progress on some of the targets, but do not specifically address the indicators. RIs in the atmospheric domain address particularly

- SDG 13 (Climate Action),
- SDG 9 (Industry, Innovation and Infrastructure; e.g., related to technological developments),
- SDG 3 (Good Health and well-being; in the atmospheric domain related to air quality as the most important research area in the future of WMO) and
- SDG 11 (Sustainable Cities and Communities), see Table 2.

Most SDGs are closely linked to each other. Climate change, representing the single biggest threat to sustainable development, and its impacts cut across most other measures of sustainable development including multidimensional poverty, equity, ethics, human security, wellbeing and climate-resilient development. Limiting global warming to 1.5°C rather than 2°C above preindustrial levels, as recommended in the IPCC Special Report 2018 (Chapter 5), would make it markedly easier to achieve many aspects of sustainable development, with greater potential to eradicate poverty and reduce inequalities.[19]

[18] CMIP is the coordination framework of the scientific climate modelling community, whose cycles (phases) are providing significant input to the IPCC assessments in the form of global climate scenarios, model evaluation and understanding of climate variability and change.

[19] See also: https://unfccc.int/achieving-the-sustainable-development-goals-through-climate-action; Many of the issues discussed in Chapter 9 of Agenda 21, on "Protection of the Atmosphere," are also addressed in such

D12.1 of the ENVRIPLUS project provides an analysis on the relevance of some of the RIs (of the atmospheric domain: EISCAT_3D, IAGOS, ICOS, ACTRIS, IS-ENES) for the Grand Challenges defined in other classifications and provide comparable profiles of RIs in terms of their focal Grand Challenges. The following classifications were included:

- European Commission's (EC) Societal Challenges for Europe 2020[20] (as priorities for the H2020 programme)
- ICSU Earth System Science for Global Sustainability: The Grand Challenges[21]
- US National Research Council (NRC) Grand Challenges in Environmental Sciences[22]

Initially, the ESFRI Grand Research Challenges, which were used for the 2014 ESFRI environmental RI interoperability and landscape analysis (Asmi et al., 2014[23]), were included as well, but turned out to be redundant. The ICSU classification reflects a 'workflow' view, while the EC and NRC challenges are 'topical', with a more societal/political focus for the EC challenges and a stronger research/development aspect for the NRC classification. Of particular importance for the RIs of the atmospheric domain are

- EC Grand Challenge 7 (Climate: Develop global environmental observation and information systems), and further
- EC Grand Challenge 6 (Climate: Fighting and adapting to climate change; esp. IS_ENES, ICOS, IAGOS) and
- EC Grand Challenge 8 (Security: Enhance the resilience of society against natural and man-made disasters; esp. ACTRIS),

and with regard to the NRC classification:

- Grand Challenge 1 (Biogeochemical Cycles; esp. ICOS),
- Grand Challenge 2 (Biological Diversity and Ecosystem Functioning) and
- Grand Challenge 3 (Climate Variability; esp. ACTRIS, IAGOS, IS-ENES).

In contrast, EISCAT_3D addresses particularly NRC Grand Challenge 4 (Hydrologic Forecasting).

As the atmosphere directly affects human wellbeing and daily life, atmospheric research is one of the more visible scientific fields to the general public and policy-makers. In view of air pollution, climate change and natural hazards, a better understanding, monitoring and predictive long-term (climate) modelling are of utmost importance to tackle future challenges. Informed decisions of policy-makers are dependent on the sustainable provision of the relevant standardised data and services, for which research infrastructures are developed. With regard to climate change for example, some of the RIs provide standardised observations of the compounds causing radiative forcing (see Figure 1), which is translated into knowledge on the current state of the climate, its drivers and future development (climate modelling by , e.g., IS-ENES) to inform the public and policy-makers through the IPCC Assessment Reports.

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international agreements as the 1985 Vienna Convention for the Protection of the Ozone Layer, the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer as amended, the 1992 United Nations Framework Convention on Climate Change and other international, including regional, instruments, see https://sustainabledevelopment.un.org/content/dsd/susdevtopics/sdt_atmosphere.shtml

[20] http://ec.europa.eu/programmes/horizon2020/en/h2020-section/societal-challenges

[21] www.icsu.org/news-centre/press-releases/2010/scientific-grand-challenges-identified-to-address-global-sustainability

[22] www.nap.edu/catalog/9975/grand-challenges-in-environmental-sciences

[23] Global warming, climate change, volcanoes, energy, epidemic diseases, chemicalisation, earthquakes, air quality, fresh water, ocean acidification, deforestation, biodiversity loss, food supplies

Each RI has its own scientific focus and provides data and services to answer specific questions. However, addressing Grand Challenges needs interdisciplinary research utilising the output of several RIs (and other data and information sources) which are complementing each other (section A.4). Furthermore, as described above, the Grand Challenges are closely linked to each other, whereby potential solutions for one of them might not be the optimal solution for another one (e.g., interrelations of air pollution and climate change). Working on the evolution of the infrastructure and towards a refinement of their role in the landscape and portfolio to address constantly evolving issues is a general need for every infrastructure whatever his maturity. For example, within its current project, EUROCHAMP is working on the evolution of its chamber infrastructure to address broader scientific and societal needs, e.g., climate change drivers, air quality impact on human health, and cultural heritage, and the development of new measurement technologies towards a carbon balance.

TABLE 2: MISSIONS OF THE RIS, WHICH SDGS ARE ADDRESSED AND HOW.

RI	Mission	SDGs addressed	How the SDGs are addressed in detail
ACTRIS	Observations of aerosols, clouds and trace gases for air quality and climate research.	Good Health and Well-being (3)	Simulation chambers, observations on air quality
		Affordable and Clean Energy (7)	Emissions, transport processes, test beds
		Industry, Innovation and Infrastructure (9)	New technical solutions, data products, satellite and modelling collaboration and development
		Sustainable Cities and Communities (11)	Analysing the impact of changing transport policies, actions and mobility, air quality of the cities
		Climate Action (13)	Impact of short-lived climate forcers, interlinkage of air quality and climate
		Life below water (14)	Measuring volatile organic compounds (VOCs)
		Life on land (15)	Measuring VOCs
ARISE	Establish an atmospheric research and data platform in Europe, which combines a large set of complementary observations and modelling studies to better describe the dynamics of the middle and upper atmosphere.	Climate Action (13)	• Determine the evolution of the atmospheric disturbances in relation to climate change by providing observations of climate-related phenomena over large time periods (to better understand the processes involved and to characterize their evolution in relation to climate change) • Improve representation of large-scale gravity and planetary waves play in stratosphere resolving climate models to estimate the impact of stratospheric climate forcing on the troposphere and developing methods to parameterize gravity waves in the perspective of future assimilation in weather forecasting models

RI	Mission	SDGs addressed	How the SDGs are addressed in detail
		Sustainable Cities and Communities (11)	Develop tools for civil applications related to monitoring of natural hazards (e.g. remote volcano monitoring for civil aviation safety)
EISCAT_3D	Observe the atmosphere and near-Earth space environment above the Fenno-Scandinavian Arctic to investigate how the Earth's atmosphere is coupled to space. (EISCAT_3D rather focusses on basic physics research instead following GCs)	Climate Action (13)	Direct observations of how the Earth's atmosphere is affected by changes in the external conditions, which are observed by EISCAT_3D.
		Industry, Innovation and Infrastructure (9)	Protecting fundamental infrastructures (power grids, navigational satellites) by helping the provision of mitigation strategies responding to space weather conditions, through observations and input to models. Providing testbed for innovative radar techniques.
EUFAR (Atm.)	Ensure that aircrafts and equipment are available across Europe for environmental research, the efficiency in operation and the (easy) availability of respective observational data (operational airborne environmental research).	Climate Action (13)	Provide observations to enable the quantification of key atmospheric and biospheric processes and composition (including anthropogenic pollutants), leading to improved model forecasts
EUROCHAMP	Significantly enhance the capacity for exploring atmospheric processes by utilisation of atmospheric simulation chambers providing different (controlled) conditions for studying how a compound will be transformed in the atmosphere (changes in chemical and physical properties)	Good Health and well-being (3)	EUROCHAMP deeply contributes to this Goal, as its focus studies are on air pollution. In particular, one of the objectives of EUROCHAMP is to investigate the links between air pollution and human health; precisely by investigating the effects that specific air components and mixtures of components can have on the human body and on its functionalities. By better defining which chemical components in the air are harmful for humans and in which percentages, EUROCHAMP studies wish to contribute to improve humans overall health level and well-being.
		Climate Action (13)	EUROCHAMP contributes by providing advancements in the understanding of air pollution, which deeply contributes to the ongoing

RI	Mission	SDGs addressed	How the SDGs are addressed in detail
			global warming, and is an important death causes in some world's areas: the RI studies the formation of primary and secondary pollutants, whose knowledge is fundamental to find and eliminate pollution sources, which are deeply investigated; such information can be very valuable for policy makers to take better action to fight such sources.
		Industry, Innovation and Infrastructure (9)	EUROCHAMP RI contributes to this goal by providing the framework, through its Transnational Access programme, for many research collaborations between scientists and private companies, often with the goal to develop new instruments for pollution detection or air composition analysis
		Sustainable Cities and Communities (11)	EUROCHAMP contributes through differents activities: firstly, the results of the RI's studies on the possible sources of air pollution can be used by policy makers to take important decisions on factories' emissions, transport limits in urban areas, energy efficiency of buildings; this can lead to an improvement of the overall liveability of cities and to the creation of new, sustainable urban areas. Secondly, one of the RI's research topics is the study of the reactions of specific chemical components in the air on the cultural heritage of cities, and the possible solution to better preserve such heritage through the years from harmful pollution sources.
HEMERA	Facilitate atmospheric research by utilising stratospheric balloons (scientific fields: atmospheric chemistry/ dynamics, astronomy, technology, vertical profiles/ light instrument validation, meteorological	Climate Action (13)	Some TNA users want to tackle climate science questions and many in combination with air quality questions, themes are, e.g., radiation and GHG profiles, stratospheric aerosols and trace gases, ions in the stratosphere, noctilucent clouds, space weather
		Good Health and Well-being (3)	Some TNA users want to tackle air quality questions (see above)

RI	Mission	SDGs addressed	How the SDGs are addressed in detail
	phenomena in the earth and sea-atmosphere boundary layer)	Industry, Innovation and Infrastructure (9)	Space companies want to test new equipment
IAGOS	Global measurements of atmospheric composition on a regular basis with focus on the tropopause region, which is most sensitive to climate change, and tropospheric columns.	Climate Action (13)	Long-term measurements of GHG and short-lived climate forcers at global scale for further evaluation of regional and global models
		Good Health and Well-being (3)	Long-term measurement of "air quality relevant variables" at global scale for further evaluation of regional and global models
		(in future maybe also Industry, Innovation and Infrastructure (9))	(in case there will be as standard measurement setup in all in-service aircrafts)
ICOS	Provide long-term observations required to understand the present state and to predict the future behaviour of the global carbon cycle and greenhouse gas emissions. ICOS (Atmosphere): large-scale monitoring of atmospheric GHG concentrations	Climate Action (13) and relating to: Affordable and Clean Energy (7) Life on land (15) Life below water (14) Zero Hunger (2) Sustainable Cities and Communities (11)	(see mission)

RI	Mission	SDGs addressed	How the SDGs are addressed in detail
		Responsible Consumption and Production (12)	
IS-ENES	Understanding and predicting climate variability and change with climate modelling, facilitating model development and supporting WCRP internationally coordinated climate simulations.	Climate Action (13; which is related to many others)	Provision of reference climate model data for future scenarios in support to mitigation and adaptation policies. Provision of reference simulations to support understanding on climate variability and change.
SIOS	A regional observational system for long term acquisition and proliferation of fundamental knowledge on global environmental change within an Earth System Science perspective in and around Svalbard. SIOS develops and implements new methods for how observational networks are to be developed in the Arctic and Polar regions.	Climate Action (13)	To understand how and which are the main drivers climate change will impact the vulnerable Arctic environment helps to target mitigation and adaptation actions.
		Industry, Innovation and Infrastructure (9)	SIOS supports actively new innovations in observation techniques and methodologies to reduce the environmental footprint of measurements.

A.2 Competence portfolios and the coverage of core variables in atmospheric research

There are several RIs in the atmospheric domain with worldwide unique features, e.g., observations of the middle atmosphere (ARISE), the only next-generation radar system (EISCAT_3D) or the number of variables observed by ACTRIS. As written in the ESFRI roadmap: "The European atmospheric research community is well recognised at an international level and in many specific research topics it has an undisputed leadership."

A.2.1 Competence portfolios

TABLE 3: CORE COMPETENCES OF THE RIS.

RI	Core competences
ACTRIS	- long-term, continuous observations for 135 short-lived atmospheric compounds in the natural atmosphere (remote sensing/ in situ), covering clouds (more frequent than the usual orbital remote sensing data), aerosols, trace gases and precursors (supporting the aerosol and ozone ECVs) - experiments in atmospheric simulation chamber (see EUROCHAMP)
ARISE	- Integrates observations to a 3D image of large-scale atmospheric dynamics and disturbances (e.g., gravity waves and tides, regional stratospheric anomalies): infrasound, LIDAR, airglow, radars, ionospheric observations and satellites - altitude range covers the middle and upper atmosphere where routine, high resolution observations are rare (Combining middle-atmospheric sounding techniques helps to better describe the interaction between atmospheric layers in poorly sampled altitude ranges and better captures the influence of large-scale atmospheric disturbances such as planetary and gravity waves, stratospheric warming or thunderstorm convection on the general circulation.) - IMS infrasound network developed fot BTBT verification is larger and much more sensitive than any before - dataset covering already 10-15 years (LIDAR data and infrasound stations) allows the investigation of broader scientific questions, e.g. effect of climate change (lightning, gravity waves), course of stratospheric temperature, locating ice-breaking in polar regions - observations could improve accuracy in short- and medium-range weather forecast and climate models (temporal scales from several weeks to season) - allows monitoring of distant volcanic eruptions in support of the civil aviation (VAACs)
EISCAT_3D	- continuous (daily) 3-D incoherent scatter observations of the state of the upper atmosphere and ionosphere above the northern Scandinavian peninsula (altitude above the range of aircraft and balloon measurements and below the range of most satellite measurements; independence of cloud coverage, weather conditions and space weather events) - next generation of EISCAT is widening the research: improvements of more than an order of magnitude in the temporal and spatial resolutions of ionospheric observations compared to present EISCAT system

RI	Core competences
	- wide range of additional applications, e.g., supporting solar system and radio astronomy sciences, space weather forecasts, detecting space debris
EUFAR	- providing access to research aircrafts as all-purposes experimental platforms allowing broad portfolio of atmospheric observations and remote sensing of land/water surfaces (e.g., land-surface interactions); user-driven application - can be used in remote areas and during periods when observations are rare (e.g. not covered by in-service flights), but critical to the understanding of particular physical, chemical or biological processes (e.g. for comparison with modelling studies)
EUROCHAMP	- providing access to atmospheric simulation chambers allowing studies of the properties of atmospheric compounds, especially kinetics and mechanisms that govern ozone and photo-oxidizing species production, particulate matter formation; user-driven application - providing data basis for parameterization of models - most advanced tool to elucidate processes in the atmosphere, e.g., understanding of chemical transformation, forecast properties, quantifying secondary sources
HEMERA	- providing access to stratospheric balloons, allowing user-driven application (infrastructure not confined to atmospheric measurements) - balloons can be navigated, long-distance flights are possible, e.g. trans-Atlantic, circum polar - altitudinal coverage complements ground-based and satellite observations of trace gases, aerosols, clouds for chemical and dynamical questions
IAGOS	- high-resolution atmospheric composition measurements (GHGs, reactive gases such as ozone and precursors, aerosols, cloud particles) - regular vertical profiles over major cities and detection of long-term changes in the troposphere and lower stratosphere: UTLS layer (9-12 km altitude, critical with regard to GHG effect) - dataset covers already > 20 years - deeper understanding of atmospheric chemistry and physics - measurements with two systems installed in commercial aircrafts: > IAGOS-CORE: fully automatic measurements of fixed set of variables onboard a growing fleet of aircrafts, quasi-global/quasi-continuous measurements (every day) > IAGOS-CARIBIC: measurements of a large, flexible set of variables monthly during 4 flights of 1 aircraft
ICOS (Atmosphere)	- standardised, high-precision, continuous atmospheric concentration measurements of long-lived GHGs (and respective ancillary tracers) in the natural atmosphere from ground-based stations (esp. CO_2, CH_4) - feeding inversion or assimilation/ data fusion systems to produce GHG budget at regional/ global levels; validation/ uncertainty reduction in climate models

RI	Core competences
	- integration with observations in terrestrial/ limnic ecosystems and ocean for a multi-scale analysis of greenhouse gas emissions and carbon cycle, human and natural drivers, processes and controlling mechanisms, regional budgets
IS-ENES	- providing access to climate models and software tools for model development and use - providing access to model data from global and regional climate models (CMIP and Coordinated Regional Climate Downscaling Experiment, CORDEX[24]), including variables from atmosphere ocean, land in their physical and biogeochemical dimensions, for past, present and future climate condition
SIOS	- integration with other domains for coherent and comprehensive research in Svalbard region, answering key questions in Earth System Science (especially Arctic amplification, Arctic water cycle, anthropogenic forcing), focus on Svalbard land mass and biota interactions with changing climate; specific interest in variables that links the different domains to each other, e.g GHG fluxes or snow properties - offering access to various infrastructures in Svalbard and harvests/ assembles Svalbard-specific data - infrastructure optimisation - SIOS is coordinating the long-term monitoring, the participating stations themselves have additional campaigns - GCI-Cusp rocket campaigns to answer questions related to the energy transport through the polar atmosphere (complement the vertical coverage of observations)[25]

A.2.2 Core variables in atmospheric research and their coverage by the RIs

Atmospheric observations are essential for our scientific understanding of the Earth´s climate, and to strengthen informed decision-making. Assembling sets of relevant variables facilitates prioritisation of requirements, optimised observations and monitoring, as well as focused and coordinated action (Bojinski et al., 2014). This is of great advantage for ocean observations, considering their high costs and the difficult conditions under which they are gathered. 'Essential Variables' represent the first level of abstraction between low-level primary observations and high-level indicators of, e.g., climate and biodiversity, and thus, are of particular importance for the interaction between researchers and decision-makers. There are many systems of 'Essential Variables' on the market, e.g., developed within projects (as subset of the essential variables in the H2020 project SEACRIFOG, see López-Ballesteros et al., 2018), or the Essential Carbon Cycle Variables defined within the COCOS project). However, here we only focus on the ones developed by programmes with a clear mandate by global organisations.

While atmospheric dynamics are observed by ARISE and EISCAT_3D (the variables observed by EISCAT_3D will be electron density, electron temperature, ion temperature and drift velocity), long-term observations of its composition are performed by several other RIs in the atmospheric domain. Those conduct long-term observations of natural atmospheric composition (ACTRIS, IAGOS, ICOS) follow two variable systems, the Essential Climate Variables (ECVs) and the ones defined by the World Meteorological Organization (WMO)

[24] www.cordex.org/
[25] www.unis.no/svalbard-at-the-centre-of-a-giant-rocket-project/

Global Atmosphere Watch (GAW) (see sections A.2.2.1 and A.2.2.2). In comparison to RIs conducting observations, IS-ENES provides simulated data for many of the variables.

Comparing the portfolios of variables covered by the three RIs to the atmospheric compounds causing anthropogenic radiative forcing shows that all groups are covered by the observations of ACTRIS, IAGOS and ICOS. However, some of the IAGOS measurements (e.g., halocarbons) are taken within IAGOS-CARIBIC, whereby the measurements are conducted at regularly repeated routes of one Lufthansa aircraft.

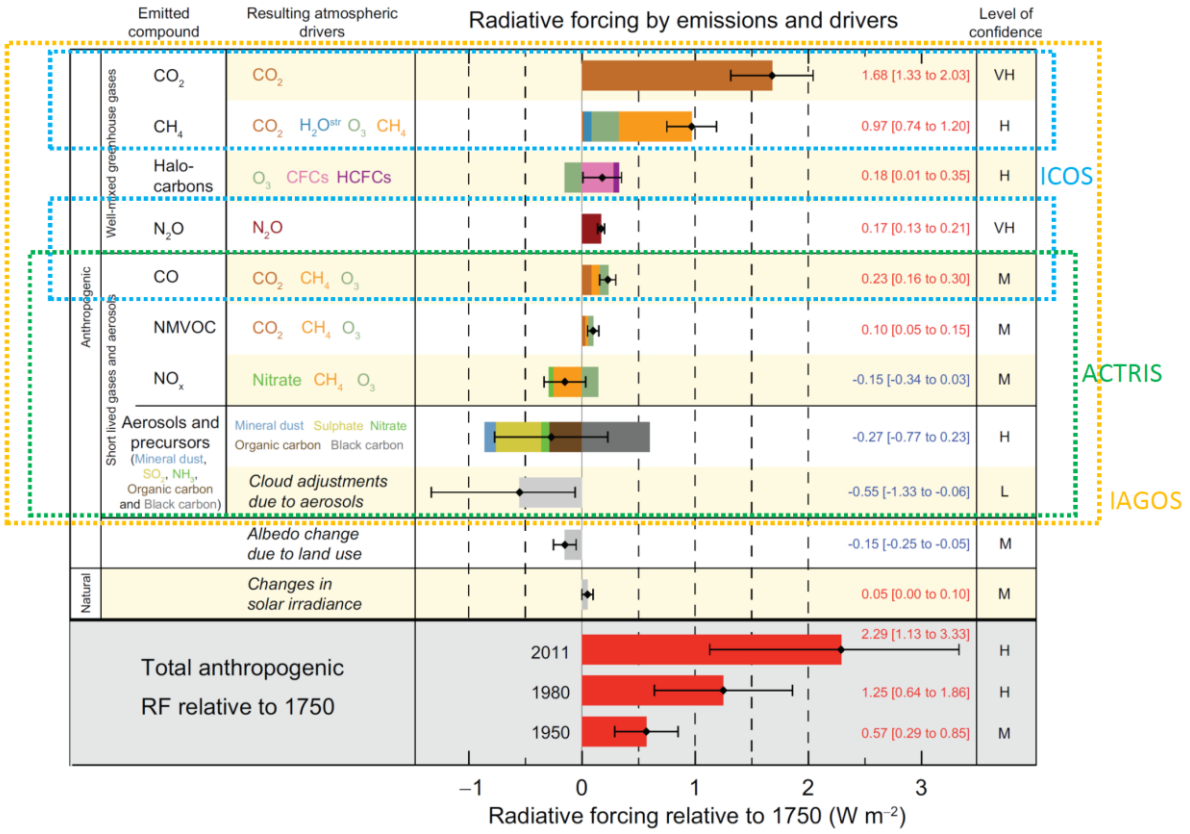


FIGURE 1: COMPOUNDS CAUSING RADIATIVE FORCING, WHICH ARE COVERED BY OBSERVATIONS OF IAGOS, ACTRIS AND ICOS, MODIFIED FROM FIGURE SPM.5 IN THE IPCC AR5 (IPCC, 2013).

A.2.2.1 Essential Climate Variables (ECVs)

An ECV[26] is a physical, chemical or biological variable or group of linked variables that critically contributes to the characterisation of Earth's climate (Bojinski et al., 2014). They represent the most mature set of 'Essential Variables', e.g., in comparison to Essential Ocean Variables (EOVs) and Essential Biodiversity Variables (EBVs). The selection of ECVs is regularly maintained by the Global Climate Observing System (GCOS) expert panels and based on three criteria: relevance, feasibility and cost effectiveness. ECVs are observed according to the GCOS Climate Monitoring Principles[27]. GCOS is a programme which regularly assesses the status of global climate observations and produces guidance for its improvement, mandated by WMO, the Intergovernmental Oceanographic Commission of UNESCO, the United Nations Environment Programme, and the International Science Council. It works towards accurate, sustained, freely and openly available global climate observations.

[26] https://public.wmo.int/en/programmes/global-climate-observing-system/essential-climate-variables
[27] http://ane4bf-datap1.s3-eu-west-1.amazonaws.com/wmocms/s3fs-public/ckeditor/files/GCOS_Climate_Monitoring_Principles.pdf?l1e4ALNYxVIStmm19we2Sz0evxEFpHmT

Systematically observing ECVs aims to solve challenges in climate research and support climate services and mitigation and adaptation measures. ECVs are broadly adopted in science and policy. Many activities globally and in Europe, e.g. in WMO, the United Nations Framework Convention (UNFCCC) and Copernicus, are structured along the ECVs. They have been identified as a key element of the observations and monitoring pillar of the WMO programme GFCS (Global Framework for Climate Services). In compliance with their purpose to tackle grand environmental challenges, RIs should contribute to sustained observations of ECVs. The ESFRI-listed RIs ACTRIS, IAGOS and ICOS together address particularly the ECVs in the two variable groups Upper Atmosphere and Atmospheric Composition, (ECVs for the atmosphere[28]), although only part of the ECV data products is provided directly by the RIs. Apart from ECV long-term observation itself, various activities of the RIs represent important contributions to systematic ECV observations. This includes the provision of supplemental observations, technological improvement, e.g., increasing the accuracy of measurements and pioneering capabilities to measure new variables (Bojinski et al., 2014). Contributions as the latter two are, particularly, related to RIs providing experimental platforms (EUROCHAMP, EUFAR, HEMERA). In one of its JRAs HEMERA is planning to define a Set of Lightweight Innovative Instruments (SLII) to provide ECV data (air pressure and temperature, wind, O_3, H_2O, CH_4, CO_2, aerosols, gamma-ray atmospheric background) for TNA users.

ECVs are broadly adopted in science and policy. Many activities globally and in Europe, e.g. in WMO, UNFCCC and Copernicus, are structured along the ECVs. They have been identified as a key element of the observations and monitoring pillar of the WMO programme Global Framework for Climate Services.

[28] See GCOS Implementation Plan 2016

TABLE 4: CURRENT LIST OF ECVS AND RESPECTIVE DATA PRODUCTS[29], WHICH ONES ARE PROVIDED BY RIS TROUGH OBSERVATIONS, WHERE QUANTITIES ARE OBSERVED BY RIS WHICH ARE CLOSELY RELATED TO THE ECV AND FROM WHICH THE PRODUCT CAN BE DERIVED, AND OTHER CONTRIBUTIONS (PROVISION OF SUPPLEMENTAL OBSERVATIONS, TECHNOLOGICAL IMPROVEMENT, E.G., INCREASING THE ACCURACY OF MEASUREMENTS AND PIONEERING CAPABILITIES TO MEASURE NEW VARIABLES).

ECV	Product (ECV dataset)	Addressed by RI		
		Provision of product	Provision of quantities from which the product can be derived	Other contributions
Upper Atmosphere				
Earth Radiation Budget	Top-of-atmosphere ERB longwave			
	Top-of-atmosphere ERB shortwave (reflected)			
	Total solar irradiance			
	Solar spectral irradiance			
Lightning	Number of lightnings			
Temperature (upper-air)	Tropospheric Temperature profile			EUFAR – in situ measurements to validate models and satellite products
	Stratospheric Temperature profile			
	Temperature of deep atmospheric layers			EUFAR – in situ measurements to validate models and satellite products

[29] Current ECV requirements according to the GCOS 2016 Implementation Plan, Annex 1:
Atmosphere: http://ane4bf-datap1.s3-eu-west-1.amazonaws.com/wmocms/s3fs-public/ckeditor/files/ECV-Atmosphere_requirements_IP2016.xls?vz8ZpZfeaewO8vVjYgSx8k204SPP3Keo
Ocean: http://ane4bf-datap1.s3-eu-west-1.amazonaws.com/wmocms/s3fs-public/ckeditor/files/ECV-Ocean_requirements_IP2016.xls?fzLV7g7QVzmWFqaZkYUBXUa_8DPq2UZZ

ECV	Product (ECV dataset)	Addressed by RI		
		Provision of product	Provision of quantities from which the product can be derived	Other contributions
Water Vapour (upper air)	Total column-water vapour	(IAGOS-CORE, IAGOS-CARIBIC: water vapour)		
	Tropospheric profile of water vapour			EUFAR – in situ measurements to validate models and satellite products
	Lower-stratospheric profile of water vapour			
	Upper tropospheric humidity			EUFAR – in situ measurements to validate models and satellite products
Wind speed and direction (upper-air)	Upper-air wind retrievals			
Cloud Properties	Cloud amount			
	Cloud Top Pressure			
	Cloud Top Temperature			
	Cloud Optical Depth	(IAGOS-CORE: cloud particle number density)		EUFAR – in situ measurements to validate models and satellite products
	Cloud Water Path (liquid and ice)		(IAGOS-CARIBIC: cloud ice/ water)	EUFAR – in situ measurements to validate models and satellite products
	Effective particle radius (liquid and ice)			EUFAR – in situ measurements to validate

ECV	Product (ECV dataset)	Addressed by RI		
		Provision of product	Provision of quantities from which the product can be derived	Other contributions
				models and satellite products
Atmospheric Composition				
Aerosols properties	Aerosol optical depth	(IAGOS-CORE, IAGOS-CARIBIC: number density, size distribution)		EUFAR – in situ measurements to validate models and satellite products
	Single-scattering albedo			EUFAR – in situ measurements to validate models and satellite products
	Aerosol-layer height			EUFAR
	Aerosol extinction coefficient profile near tropopause			EUFAR
	Aerosol extinction coefficient profile mid stratosphere			
Carbon Dioxide, Methane and other Greenhouse gases	Tropospheric CO_2 column	ICOS		
	Tropospheric CO_2	ICOS, IAGOS- CORE, IAGOS-CARIBIC, EUFAR		
	Tropospheric CH_4 column	ICOS		
	Tropospheric CH_4	ICOS, IAGOS- CORE, IAGOS-CARIBIC, EUFAR		
	Stratospheric CH_4			

ECV	Product (ECV dataset)	Addressed by RI		
		Provision of product	Provision of quantities from which the product can be derived	Other contributions
Ozone	Total column ozone			
	Troposphere Ozone	IAGOS-CORE, IAGOS-CARIBIC, EUFAR		
	Ozone profile in upper and lower stratosphere			
	Ozone profile in upper strato- and mesosphere			
Precursors (supporting the Aerosol and Ozone ECVs)	NO_2 tropospheric column	(IAGOS-CORE, IAGOS-CARIBIC: NO2), EUFAR		
	SO_2, HCHO tropospheric columns	IAGOS-CARIBIC		
	CO tropospheric column			
	CO tropospheric profile	IAGOS-CORE, IAGOS-CARIBIC: CO), EUFAR		

A.2.2.2 Variables defined by WMO GAW

In order to monitor and assess the chemical composition and related physical characteristics of the global background atmosphere (global mean atmospheric conditions), each of the six focal areas within WMO GAW (aerosols, greenhouse gases, selected reactive gases, ozone, UV radiation and precipitation chemistry) has defined a set of variables. In order to allow for comparability and interpretation of global or continental scale atmospheric data from different stations and networks, WMO provides regularly updated recommendations for the observations and sets compatibility goals, such as for the measurement of the major greenhouse gases and related tracers in the GAW report n° 213. IAGOS, ACTRIS/ EUROCHAMP and ICOS target the same compatibility goal for high-quality data.

TABLE 5: VARIABLES FOR THE MONITORING AND ASSESSMENT OF THE CHEMICAL COMPOSITION AND RELATED PHYSICAL CHARACTERISTICS OF THE GLOBAL BACKGROUND ATMOSPHERE AS DEFINED BY GAW, AND HOW THEY ARE COVERED BY THE RIS THROUGH OBSERVATIONS.

Variable subgroup	Variable	RI
Aerosols		
Physical Properties	particle number concentration (size integrated)	EUFAR
	particle number concentration (size integrated)	EUFAR
	particle number size distribution	EUFAR
	particle mass concentration (two size fractions)	EUFAR
	cloud condensation nuclei number concentration (at various super-saturations)	EUFAR
Optical Properties	light scattering coefficient (various wavelengths)	EUFAR
	light hemispheric backscattering coefficient (various wavelengths)	EUFAR
	light absorption coefficient (various wavelengths)	EUFAR
Chemical Properties	mass concentration of major chemical components (two size fractions)	EUFAR
Column and Profile	aerosol optical depth (various wavelengths)	EUFAR
	vertical profile of aerosol backscattering coefficient	
	vertical profile of aerosol extinction coefficient	EUFAR
Additional parameters recommended for long-term or intermittent observation	dependence of aerosol properties on relative humidity	EUFAR
	detailed size segregated chemical composition	EUFAR
GHGs		
	CO_2 (incl. $\Delta^{14}C$, $\delta^{13}C$ and $\delta^{18}O$ in CO_2, O_2/N_2 ratios)	ICOS, EUFAR

Variable subgroup	Variable	RI
	CH_4	ICOS, EUFAR
	N_2O	ICOS, EUFAR
	Halocarbons and SF6	EUFAR
	H2 (Molecular Hydrogen)	
Reactive gases		
	Surface O_3 (tropospheric)	
	CO	ICOS, EUFAR
	VOCs	ACTRIS, EUFAR
	SO_2	
	Oxidised nitrogen compounds (NO_x, NO_y)	ACTRIS, EUFAR
Ozone		
	Stratospheric O_3	
Radiation		
	Short-wave radiation (UV-B)	ICOS, EUFAR
	Long-wave radiation (UV-A)	ICOS, EUFAR
Atmospheric deposition		
	Dry deposition (sulfur, some nitrogen species, and a few cations)	eLTER
	Wet deposition (chemicals found in precipitation such as sulphate, nitrate, ammonium, chloride, sodium, potassium, calcium, magnesium, phosphate, fluoride, pH and acidity)	eLTER

A.3 Integration of research infrastructures into regional and global frameworks

As key elements of the European Research Area (ERA), research infrastructures are meant to be strongly integrated into European and global frameworks in order to exploit their full potential. ESFRI supports a respective coherent and strategic approach, which is complemented by RIs and projects not listed on the roadmap. The most intensive links of the atmospheric domain exist to WMO (GAW), Copernicus and the European pillar of GEO, particularly for the ESFRI-listed RIs which are addressing air quality and climate

change. EISCAT_3D has already international partners built in and is connected to other global frameworks. IS-ENES is strongly linked to WCRP.

See sections A.3.1 and A.3.2 for details on relations with WMO (GAW) and Copernicus services.

TABLE 6: INTEGRATION OF RIS INTO EUROPEAN AND GLOBAL FRAMEWORKS AND THEIR CONTRIBUTION TO INTERNATIONAL PROJECTS OF INTEREST FOR THE ATMOSPHERIC DOMAIN AND DATA STREAMS TO EUROPEAN AND GLOBAL DATABASES

RI	Integration into regional and global frameworks/ Contribution to projects and databases
ACTRIS	- involved in NextGEOSS data hub and the project INTAROS - supporting EUMETNET, EUMETSAT, ESA - Develops international reference procedures (for EURAMET; CEN/ ISO standards; ACTRIS requests to be associated to the European Metrology Network on ECVs) - operating jointly with EMEP the EBAS (Topical Centre for near-surface data on aerosol and trace-gases, linked to WMO GAW)
ARISE	- links to EuroGEOSS
EISCAT_3D	(EISCAT data: upper atmospheric science database Madrigal[30])
EUFAR	(data streams to regional and global databases depend mainly on the users) - Supports Research and Development Projects of the World Weather Research Programme (under WMO). Flight projects also support ESA, EUMETSAT - Databases at CEDA (UK) and AERIS (France) are publicly-accessible
EUROCHAMP	(data streams to regional and global databases depend mainly on the users)
HEMERA	(data streams to regional and global databases depend mainly on the users)
IAGOS	- provides data to GEOSS
ICOS	- Regional network in WMO GAW, connected to WMO IG^{3}IS - TCCON might be integrated into ICOS and is supported by ESA - involved in H2020 projects VERIFY and SEACRIFOG to design concepts for enhancing MRV and global stocktake - ICOS ATC to be associated to the European Metrology Network - connections to EOSC, RDA
IS-ENES	- supports WCRP international coordinated experiments CMIP and CORDEX - IS-ENES3 contributes through CMIP6 to IPCC AR6 report
SIOS	- member institutions provide data measured in Svalbard to various databases like EMEP

[30] http://cedar.openmadrigal.org/openmadrigal

Global frameworks and initiatives

The Group on Earth Observations (**GEO**) is a global network/ partnership of more than 100 national governments and more than 100 Participating Organizations. GEO is advocating for informed decisions and actions for the benefit of humankind by coordinated, comprehensive and sustained Earth observations. The construction of the Global Earth Observation System of Systems (GEOSS) is a central part of GEO´s mission. GEO's global engagement priorities include supporting the UN 2030 Agenda for Sustainable Development, the Paris Climate Agreement and the Sendai Framework for Disaster Risk Reduction. The GEO initiative 'Earth Observations in Service of the 2030 Agenda' aims to support efforts to integrate Earth observations and geospatial information into national development and monitoring frameworks for the SDGs. European efforts in GEO are supported through the EuroGEOSS initiative (see below). The GEO Carbon and GHG Initiative (**GEO-C**) is aiming to facilitate cooperation to develop a coordinated, observation system across domains for monitoring and evaluating changes in the carbon and other cycles, and GHG emissions and to provide decision-makers with timely and reliable policy-relevant information. The most relevant policy framework for GEO-C is the Paris Agreement on Climate Change. Activities of ICOS in GEO-C (secretariat) ended recently since the orientation of GEO-C has changed towards observations by remote sensing.

The Global Earth Observation System of Systems (**GEOSS**) is an integrated set of coordinated, independent Earth observation, information and processing systems provided by countries and organisations within GEO. The goal is to collect and share environmental data, information and knowledge (via a single access point) with public and private sectors. So far, it comprises mainly NASA data and, particularly, remote sensing data. Nevertheless, its biggest contribution (advantage) is that it defines the best-practices in different fields of Earth observation, which were developed based on a community consensus. RIs can refer to the best-practices in order to justify their methodology.

The Intergovernmental Panel on Climate Change (**IPCC**) is an independent body founded under the auspices of WMO and the United Nations Environment Programme (UNEP). It assesses the scientific, technical and socioeconomic information relevant for the understanding of the risk of human-induced climate change. It provides comprehensive Assessment Reports, incorporating summaries for policy-makers, which are widely recognized as the most credible sources of scientific information on climate change. IPCC serves the needs of the Conference of Parties (COP) to the United Nations Framework Convention (UNFCCC), which develops and implements respective policy responses. The Subsidiary Body for Scientific and Technological Advice (SBSTA) is one of the two permanent subsidiary bodies to the Convention. It provides timely information and advice on scientific and technological matters as they relate to the Convention, its Kyoto Protocol and the Paris Agreement. In 2018, the IPCC published a special report on the impacts of global warming of 1.5°C. The scientific community is currently working on CMIP6, led by the World Climate Research Programme (**WCRP**), which will include scenarios that limit warming in 2100 to below 1.5°C relative to pre-industrial levels, and the range of impacts at the regional and local levels associated with these scenarios. The Global Carbon Project **(GCP)** is a global research project of Future Earth and a research partner of WCRP that integrates knowledge of GHGs from human activities and the Earth system to support policy debate and action towards a climate neutral future.

The Integrated Global Greenhouse Gas Information System (**IG^{3}IS**) was initiated by WMO to develop GHG emission-reduction actions in response to climate change. The system will establish and build confidence in the role of atmospheric composition measurements as an essential part of climate change mitigation efforts.

The Research Data Alliance (**RDA**) is a community-driven initiative supported by the European Commission, the United States Government's National Science Foundation and National Institute of Standards and Technology, and the Australian Government's Department of Innovation with the goal of building the social and technical infrastructure to enable open sharing and re-use of data. RDA has a grass-roots, inclusive approach covering all data lifecycle stages, engaging data producers, users and stewards, addressing data exchange, processing, and storage.

European programmes and initiatives

The European Centre for Medium-Range Weather Forecasts (**ECMWF**) is both a research institute and an operational service, producing and disseminating numerical weather predictions to its Member States. This data is fully available to the national meteorological services in the Member States. The Centre also offers a catalogue of forecast data that can be purchased by businesses worldwide and other commercial customers. The supercomputer facility (and associated data archive) at ECMWF is one of the largest of its type in Europe and Member States can use 25% of its capacity for their own purposes. It is promoting a workshop on the use of observational campaigns to improve forecast quality. [31]

The European Monitoring and Evaluation Programme (**EMEP**) is a scientifically based and policy-driven programme under the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP) for international co-operation to solve transboundary air pollution problems.

The European Association of National Metrology Institutes (**EURAMET**) is the Regional Metrology Organisation of Europe coordinating the cooperation of National Metrology Institutes (NMI) in Europe in fields such as research in metrology, traceability of measurements to the SI units, international recognition of national measurement standards and related Calibration and Measurement Capabilities. Through Knowledge Transfer and cooperation among our members EURAMET facilitates the development of the national metrology infrastructures.

The European Meteorological Services Network (**EUMETNET**) is a network of 31 European National Meteorological Services that provides a framework to organise cooperative programmes between its Members in the various fields of basic meteorological activities such as observing systems, data processing, basic forecasting products, research and development, and training.

The European Organisation for the Exploitation of Meteorological Satellites (**EUMETSAT**) is an intergovernmental organisation supplying weather- and climate-related satellite data, images and products 24/7 to the national meteorological services of EMEP member states and other users worldwide.

The European Space Agency (**ESA**) has the mission to shape the development of Europe's space capability and ensure that investment in space continues to deliver benefits to the citizens of Europe and the world. ESA is an international organisation with 22 Member States. By coordinating the financial and intellectual resources of its members, it can undertake programmes and activities far beyond the scope of any single European country. It makes frequent use of airborne measurements to support the development of new spaceborne Earth observation technology and satellite missions.

EuroGEOSS is the European pillar of GEOSS and thereby the framework to combine the contributions of European GEO members. The recently started E-SHAPE project (EUROGEOSS Showcase: Applications powered by Europe) aims to set up and promote a sustainable organization dedicated to users' uptake of European Earth Observation resources. It builds on Copernicus and GEOSS through the development of co-

[31] www.ecmwf.int/en/learning/workshops/workshop-observational-campaigns-better-weather-forecasts

design pilots and delivering economic, social and policy value to European citizens. Copernicus data to be utilised within EuroGEOSS will be provided through DIAS.

European projects

The H2020 project **INTAROS** (INTegrated ARctic Observation System, 2016-2021) addresses the considerable in situ data deficit in the Arctic Copernicus Services have to face. The project has a strong multidisciplinary focus and will help to build an efficient integrated Arctic Observation System by extending, improving and unifying existing systems in the different regions of the Arctic. The observation system will be fit-for-purpose for many Copernicus Services. EuroGOOS is involved in the project.

NextGEOSS is a centralised European Earth observation data hub and platform, where the users can connect to access data and deploy applications. It is funded as H2020 project for the implementation of GEOSS. It is one of many H2020 projects which is supporting the implementation and development of Copernicus data and services.

Within the H2020 project **VERIFY** (Observation-based system for monitoring and verification of greenhouse gases) a system to estimate greenhouse gas emissions is developed to support countries' emission reporting to the UNFCCC Secretariat. The emissions are estimated based on land, ocean and atmospheric observations. The project focuses on the three major greenhouse gases responsible for global warming: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

A.3.1 Individual contributions to/ collaborations with WMO GAW

The Global Atmosphere Watch (GAW) is a global programme of the World Meteorological Organization (WMO) for monitoring and assessing chemical composition and related physical characteristics of the global background atmosphere. It involves the Members of WMO, contributing networks and collaborating organizations and bodies. Its focal areas are aerosols, greenhouse gases, selected reactive gases, ozone, UV radiation and precipitation chemistry (or atmospheric deposition). The missions of GAW are to: (1) reduce environmental risks to society and meet the requirements of environmental conventions; (2) strengthen capabilities to predict climate, weather and air quality; and (3) contribute to scientific assessments in support of environmental policy. GAW coordinates activities and data from 31 global stations, more than 400 regional stations, and around 100 contributing stations operated by contributing networks. WMO has seven World Data Centres (WDCs) which collect, document and archive atmospheric measurement parameters or measurement types and the associated metadata from measurement stations worldwide. These data are then made freely available to the scientific community, in some cases with additional data products such as data analyses, maps of data distributions, and data summaries. The extent of observed variables varies between GAW stations. Observations are reported voluntarily by the GAW observatories, while the station infrastructure is a contribution of the participating national authorities to the GAW Programme.

Some of the RIs in the atmospheric domain are closely linked to GAW in different aspects, e.g., as contributing networks following the WMO/ GAW standard operating procedures (SOPs) and measurement guidelines. For the coverage of GAW variables by the RIs see section A.2.2.2.

TABLE 7: LINKS OF THE RIS TO WMO GAW. (SAG = SCIENTIFIC ADVISORY GROUP, WCC= WORLD CALIBRATION CENTRE, WDC = WORLD DATA CENTRE[32])

RI	Links to GAW
ACTRIS	- collaborating network of GAW as European pillar for observations of aerosols and reactive gases - operates WDCs for Reactive Gases (surface ozone (troposphere), NO_x, SO_2) and Aerosols (VOCs, aerosol physical and chemical parameter, aerosol optical depth) ➔ implemented in ACTRIS data portal (operated by NILU) as also EMEP data ➔ procedures and formats follow same approach as for ACTRIS - operates WCCs for reactive gases and aerosols, ozone profiles, and NO_x - contributes to SAGs for reactive gases and aerosols, which defines protocols and SOPs and adopted many of ACTRIS methodology ➔ direct link to ECVs for aerosols, clouds, and reactive trace gases
ARISE	(co-location of lidar station with GAW station Hohenpeißenberg (Germany), Maïdo lidar station at Reunion Island (France) is candidate for GAW station)
EISCAT_3D	(No present links. EISCAT_3D could potentially provide input into WMO GAW through boundary conditions to atmospheric models. Connections such as these have been included as part of a recent application for EC funding.)
EUFAR	- recommending WMO standards and guidelines to TNA users - joint development of standards and protocols for atmospheric trace species measurements (GHGs, VOCs, NOx) with ACTRIS/IAGOS
EUROCHAMP	- operates WCC for Aerosol Physics - SOPs and measurement guidelines developed based on research in chambers
HEMERA	(depends on user)
IAGOS	- collaborating network of GAW (facilitates connection to other networks such as NDACC, sounding) - operates Quality Assurance/ Science Activity Centre, Central Calibration Laboratory - contributes to SAGs, e.g., for reactive gases, GHGs and aerosols - RT data will be provided through the WMO Information System (WIS) when operational
ICOS	- collaborating network of GAW (TCCON, which might be integrated into ICOS, is also a contributing member of GAW) - contributes to the SAG for greenhouse gases

[32] see also www.wmo.int/pages/prog/arep/gaw/gaw_cent_facil.html for GAW central facilities

RI	Links to GAW
	- contributing to IG^{3}IS (Integrated Global Greenhouse Gas Information System) - ICOS involved in international inter-comparison programs to assure the data compatibility with the other international networks such as WMO GAW
IS-ENES	- IS-ENES uses GAW data for modelling the atmospheric components of Earth system models used to study climate
SIOS (Atm)	- some SIOS stations contribute data to GAW - Research in Svalbard portal: annotation is standardised following the WMO standards in order to make entries unambiguous and interoperable internationally

A.3.2 Individual contributions to/ collaborations with Copernicus services

Observational research infrastructures are important in situ data sources for the European Union's Earth observation programme Copernicus, which offers information services based on satellite Earth observation, in situ data (ground-based, sea-borne or air-borne monitoring systems, as well as geospatial reference or ancillary data) and modelling. By adding value to 'raw' data products from the data providers, Copernicus develops information products to support policy-makers.

Of particular interest with regard to the atmospheric domain are two of the six Copernicus services: the Copernicus Atmosphere Monitoring System (CAMS) and the Copernicus Climate Change Service (C3S)[33]. Both are implemented by the European Centre for Medium-Range Weather Forecasts (ECMWF) on behalf of the European Commission and important users of in situ data provided by ACTRIS, IAGOS and ICOS. The data provided are level 1 or 1.5 (quality controlled) atmospheric concentrations of chemical species or their (physical) properties, provided in real-time (RT), near real-time (NRT) or delayed mode.

CAMS is a follow-up of the Global Monitoring for Environment and Security (GMES) and Monitoring Atmospheric Composition and Climate (MACC) programmes. It provides consistent and quality-controlled global information related to atmospheric composition. CAMS collaborates with a wide range of European organisations providing satellite (e.g., ESA and EUMETSAT) and in situ observations. These are needed to constrain the air quality models at the near-surface level of exposure and to validate the global and regional forecasts and reanalyses, i.e., to quality control the combined information from models and satellite observations. CAMS provides daily NRT information on the global atmospheric composition by monitoring and forecasting components, greenhouse gases, reactive gases, ozone and aerosols. It also conducts global reanalyses to track the atmospheric composition over several years and produces daily European air quality analyses and forecasts with a multi-model ensemble system. The most urgent challenge of CAMS is a more sustainable funding for in situ observations, which is addressed, e.g., by RIs in the atmospheric domain.

The CAMS in situ data requirements on atmospheric composition are:

- Concentrations of major air pollutants (e.g., NO_x, PM_{10}, $PM_{2.5}$, CO, SO_2, HCHO, Pb, TSP, C_6H_6)
- Improved observation of size resolved chemical composition of aerosol
- Improved global observations of GHG concentrations and related species (e.g., CO_2, CH_4, N_2O, ^{14}C)

[33] A report providing mitigation steps to overcome risks, challenges and gaps in the contributions of RIs to Copernicus services is available here: http://eurogoos.eu/download/project_deliverables/Copernicus-2017-and-Research-Infrastructures.pdf.

- Vertically resolved concentration data of pollutant gases and aerosols
- Solar radiation and UV

The CAMS database would benefit from contributions of networks such as the global TCCON and AirCore.

TABLE 8: INDIVIDUAL IN SITU DATA CONTRIBUTIONS OF IAGOS, ICOS AND ACTRIS TO CAMS.

RI	Individual in situ data contributions
ACTRIS	- provides aerosol vertical profiles and advanced composition measurements in Europe - ACTRIS provides RT and NRT atmospheric profiles of O_3 (UTLS) & aerosol properties, which are critical for validation of forecasts - **Monitoring air quality/ Regional models:** ACTRIS data used for model assessments (Integrated Forecast System), e.g., prototype for evaluation and online verification of models available from CAMS site using aerosol scattering coefficient from ACTRIS & GAW sites (within ACTRIS-2 verification activities)
IAGOS	- IAGOS involved in GEMS and MACC since 2005 - O_3, CO and water vapour are planned to be delivered in NRT during aircraft journey - data critical for forecast and validation, in particular for data provided during aircraft ascent and descent near airports - IAGOS offers unique capacity to test model performances globally - **Monitoring air quality/ Regional models:** IAGOS involved in validation of regional and global models in forecast and reanalysis modes (up to 5000 m, European airports, 10 km resolution) **- NRT monitoring of global atmospheric composition:** Profiles of O_3 and CO from the CAMS NRT forecast with and without assimilation are validated with profiles from IAGOS at the airports visited each day - **Reanalysis of atmospheric composition:** O_3 and CO from the MACC reanalyses are validated with profiles from MOZAIC/IAGOS and from IAGOS-CARIBIC aircraft for the period 2003-2008; IAGOS provides timeseries and climatologies of O_3 and CO (MOZAIC, IAGOS) for validation of CAMS reanalysis, with focus on upper troposphere–lower stratosphere (UTLS)
ICOS	- ICOS provides NRT (24h) atmospheric GHG concentration data, which are critical for validation of global and regional forecasts to establish a data stream that is fit-for-purpose for validation activities, CAMS will support the improvement of the robustness and management of a reliable preparation, transmission and quality control of rapid delivery atmospheric ICOS data, the development and implementation of diagnostic software to handle instrumental anomalies in the data, and to detect physical anomalies in the observations that might impact the validation of the CAMS forecast products

With C3S, Copernicus aims to provide and visualise the ECVs defined by GCOS, and develop information about past, current and future states of the climate in Europe and globally. Products provided include

- consistent estimates of key climate variables
- global and regional reanalyses covering atmosphere, ocean, land, carbon
- data sets of past and present observations
- a near-real-time climate monitoring facility
- multi-model seasonal forecasts and climate projections at global and regional scales.

The major goals of C3S are the protection of citizens from climate-related hazards and the improved planning of mitigation and adaptation practices. C3S requires long, high-quality and consistent data series of the ECVs needed to detect climatic trends of, e.g., the frequency of extreme climatic events that may have a severe impact on society. In situ data are used for climate reanalysis, as they provide essential information about the past climate, its variability and change; calibration and validation of satellite observations for the production of multi-decadal Climate Data Records with global coverage (information on many ECVs); and the evaluation and improvement of climate models by comparing model output with observations of the current and past climate, using historical forcings. C3S is still in development and gradually including the ECVs. For the individual in situ data contributions to C3S (i.e., coverage of ECVs) by ICOS, ACTRIS and IAGOS see section A.2.2.1.

IS-ENES contributes to the Copernicus Climate Change Service (C3S) through supporting the data base for climate projections brokered by C3S. Five projects are led by IS-ENES teams related with accessing the Earth system grid federation database for global (CMIP5) and for regional (CORDEX) data, providing tools for model evaluation, realising complementary set of regional climate projections for Europe and preparing a roadmap for climate projections.

The Data and Information Access Services of Copernicus (DIAS) are a set of cloud-based platforms with central access to Copernicus data and information. Direct data flow from the RIs to DIAS is not yet operational.

There are no formal collaborations (yet) between Copernicus Services and EUROCHAMP, EUFAR, HEMERA, SIOS, ARISE and EISCAT_3D (since the spatial coverage volumes do not intersect).

A.4 Complementarities between the research infrastructures

An important prerequisite of successful collaboration and integration is to detect the complementarities between the RIs. IAGOS, ACTRIS and ICOS (Atmosphere) are complementary by jointly monitoring on the long term many of the ECVs defined by GCOS (see section A.2.2.1). Whereas IAGOS is aiming for a global coverage of high-altitude measurements by using fixed commercial flight routes, (however, measuring quasi-continuously only), observations in ACTRIS and ICOS are temporally continuous and distributed across Europe. In addition, IAGOS measures vertical profiles nearby airports. ACTRIS atmospheric composition measurements, which cover the near-surface to high-altitude (vertical profiles and total-column), are complementary with IAGOS measurements, providing the required spatial and temporal dimension by measuring vertical profiles of the physical properties of the atmosphere. Complementarities between ICOS and ACTRIS are related to the measurements of long-lived climate forcers by ICOS and short-lived climate forcers by ACTRIS as part of their portfolio of short-lived pollutant observations.

In comparison to IAGOS, where standard instrument packages are used for monitoring, EUFAR offers access to experimental airborne platforms, where the instrumentation depends on the user needs and can be focused on particular physical processes, yielding a huge variety of platform applications including tests of new instruments and optimisation of instrument deployment. Moreover, observations from EUFAR aircrafts are flexible in time and flight route, offering the exploration of atmospheric composition in remote

areas. IAGOS and EUFAR are partly using the same techniques and instruments, however, differently applied.

Strong synergies are expected from the merging of EUROCHAMP and ACTRIS, which are already converging progressively. In addition, EUROCHAMP has potential strong complementarities with IAGOS and ICOS. Whereas in ACTRIS and IAGOS long-term changes and trends in the atmospheric composition are detected by long-term monitoring of a huge variety of compounds, the atmospheric simulation chambers of EUROCHAMP are dedicated to study atmospheric processes and the properties of the atmospheric compounds to understand and explain what is observed in the field. In turn, the chambers are used to determine the basic parameters of interest for the monitoring, and to develop measurement standards and protocols (part of JRAs), which can then be used by ACTRIS and IAGOS to optimise the observations. Furthermore, atmospheric chamber studies are fundamental for parameterisations in air quality and climate models. (Most of the parameters included in the chemical modules of modern Chemistry-Transport Models, used for operational and research grade forecasts of air quality, have been built using chamber data.) The performance of the models can then be evaluated by long-term observations. Some links exist to ICOS, since GHGs are not in the focus, however, occasionally addressed in chamber studies, e.g., with regard to their global warming potential. Several RIs have a strong interest in testing their instruments in atmospheric simulation chambers (see section A.5.1).

EUFAR and HEMERA complement each other by offering access to aircrafts and balloons as experimental platforms for observations in the troposphere, and in the future potentially also in the stratosphere. Indeed, in its long-term strategy EUFAR wants to include an aircraft for measurements in the stratosphere. Under discussion are the research aircraft 'Geophysica', which has occasionally been available to European researchers and the DLR aircraft 'HALO', which is, however, not yet available for international campaigns. Their collaboration might define the extent to which balloons can supply all the observational needs and where aircraft may still be required. So far, balloons are the most important method for stratospheric measurements. However, they cannot be used exclusively but are instead complementary to satellite, aircraft and ground-based measurements.

EISCAT_3D is at the present not well connected to the other Ris in the atmospheric comain. However, there is great potential for complementary activities with ACTRIS and IAGOS, e.g., with regard to the altitudinal coverage. EISCAT_3D covers ice clouds in the mesopause, aerosols (dust) up to 100 km and sometimes even in the stratopause, and reactive gases (ozone, NO_x) up to the mesopause with a gap in the stratosphere (since there are no electrons which bounce back the radar signal). Furthermore, observations of both EISCAT_3D (and EISCAT) and ARISE complement each other for the study of the coupling between atmosphere and ionosphere. Disturbances of the global circulation system producing e.g. stratospheric warming in polar regions have to be taken into account in NWP models to improve medium range weather forecasting.

IS-ENES is complementary to all the other RIs in the atmosphere but also in the oceans or over land. IS-ENES is a user of observations (in situ observations from RIs, field campaigns, meteorological datasets, reanalyses and satellite data) in the different components of the climate system, especially for validation model components. Other RIs can also be users of climate model simulations, especially for recent past, to help interpret observed data. IS-ENES has also a strong expertise on data and metadata standards, including FAIR principles[34], which was used within ENVRIPLUS, e.g., on provenance.

[34] A set of guiding principles to make data Findable, Accessible, Interoperable, and Reusable, see www.force11.org/group/fairgroup/fairprinciples

A.5 Collaborations

A.5.1 Collaborations between the research infrastructures

This section includes general aspects on the collaboration between the RIs in the European ENVRI landscape and some concrete examples for collaborations between the RIs contributing to the atmospheric domain.

Tackling the grand environmental challenges calls for comprehensive collaboration between RIs and domains in data collection and analysis, and in the development of products and services. Stronger collaboration between RIs is certainly expected by the European Commission and the national funding ministries in order to expose their joint potential and enable the international scientific community to derive the full value from the investments in these large-scale environmental infrastructures.

However, it can take time to see the benefits of (early) collaboration. RIs are in risk of establishing thorough collaborations only when the RI has reached a certain level of maturity, as in the beginning it appears more important to get the RI operational and to concentrate on providing services for their own disciplines and stakeholders. However, this bears the risk of a duplication of efforts and of missing synergy effects and inefficient use of resources, hampering the contribution of RIs to a holistic understanding. Furthermore, it is getting much harder to align certain aspects when the RIs are fully established and to integrate efforts in regional and global frameworks such as GEOSS.

The atmospheric community involved in RIs is in very frequent exchange, also because the same organisations are normally involved in different RIs. Regular interdisciplinary exchange and collaboration are further particularly fostered by the ENVRI projects. In addition, the Board of Environmental Research Infrastructures (BEERi) established under ENVRIPLUS has been a major forum for the cooperative work between RIs of different domains.

The collaboration between the different RIs include:

- Exchange of knowledge/ experience (e.g., on the ERIC process, TNA) and contributing in the committees and advisory boards of one another
- Development of common products within the projects (e.g., ENVRI, ENVRIPLUS, EOSC)
- Standardisation/ harmonisation of data management (quality control, data interoperability, common databases)
- Exchange of data (e.g., for data validation, modelling)
- Joint research on common topics
- Provision of services (e.g. chamber access for calibration)
- Exchange of calibration and measurement standards
- Technical development at experimental platforms
- Operation/ sharing of infrastructure at co-located sites

Site co-locations exist, also with RIs of the terrestrial ecosystem domain or at so-called “supersites” (see Table 9), e.g., the SMEAR stations (as cornerstone of INAR RI, see section A.10) and at Svalbard (SIOS, ACTRIS, ICOS, in future potentially HEMERA, also EISCAT).

The reasons for the merging of EUROCHAMP and ACTRIS are scientific and technical synergies (see above) and the critical sizes of both RIs.

Table 9 gives an overview on the existing and planned collaborations between the RIs.

EISCAT_3D is looking forward to more intense interaction with ARISE and ACTRIS. Links to ARISE already exist via the users of the infrasound network. Connections of EISCAT and SIOS are planned through their

stations in Svalbard, within the GCI-Cusp rocket programme. This programme uses ground-based instruments, modelling, sounding rocket investigations, and satellite-based instruments to determine the multi-scale physics of heating and precipitation in the ionosphere specific to the geomagnetic cusp region. EISCAT_3D has no formal MoUs with other RIs, but with other incoherent scatter facilities outside of Europe.

ARISE has good links to the other RIs, however, common subjects are rare.

EUFAR is seeking to implement common metadata standards with closely-related RIs (IAGOS, ACTRIS).

Collaborations of SIOS with other RIs are mainly restricted to data exchange and shared infrastructure at supersites. Apart from Zeppelin Observatory, it has a co-location with ICOS (ocean) at the site Hausgarten. SIOS is aiming for further site co-location to develop supersites for a more integrated research in the Svalbard region.

Many (atmosphere and terrestrial ecosystem) sites of ACTRIS and ICOS are co-located. Collaborations to RIs in the other environmental domains are limited, with ICOS and ACTRIS being the most active ones, in case of ICOS due to its multi-domain structure. ACTRIS is collaborating with AQUACOSM and AnaEE regarding TNA access.

IS-ENES is working with ICOS in one of the science demonstrators called ERFI (in the field of environmental and earth science) as part of the EOSCpilot. The demonstrator uses the European Grid Infrastructure (EGI) Open Data Platform to develop a data integration framework for sharing datasets between ICOS and IS-ENES. Apart from this, IS-ENES does not have explicit collaboration with other RIs. However, it harvests data from their portals (ICOS, IAGOS and ACTRIS, but also Euro-Argo, AnaEE) for model evaluation and delivers, in turn, radiative fluxes, e.g., to ICOS and ACTRIS. It is involved in ENVRIPLUS with regard to data provenance (WP8).

TABLE 9: OVERVIEW ON COLLABORATIONS AND CO-LOCATIONS BETWEEN THE RIS INVOLVED IN THIS ANALYSIS. BLACK AND GREY SCRIPT INDICATE EXISTING AND PLANNED COLLABORATION, RESPECTIVELY. (TGOE = TRACEABILITY IN GAS-PHASE OBSERVATIONS IN EUFAR; JRA IN EUFAR2)

		Co-locations									
		ACTRIS	**ARISE**	**EISCAT_3D**	**EUFAR**	**EUROCHAMP**	**HEMERA**	**IAGOS**	**ICOS (Atm)**	**IS-ENES**	**SIOS (Atm)**
Collaborations	**ACTRIS**			> plans to collaborate in ozone measurements, aerosols (covering different altitudes)				> loose coordination meetings > developing common projects and products on European and national (French) level > connections through Advisory Boards	Cabauw, Kosetice, Hyltemossa, Norunda, Hohenpeissenberg, Jungfraujoch, Hyytiälä, Pallas, Lampedusa, OPE, Zeppelin, Birkenes, Saclay and Puy de Dome	*(not relevant)*	Zeppelin Observatory
	ARISE	> potentials for joint research need to be checked		> exchange, e.g. on determination of the type of atmospheric disturbance which could impact the ionosphere > in ARISE3 stronger involvement of EISCAT_3D planned						*(not relevant)*	
	EISCAT_3D									*(not relevant)*	
	EUFAR	> improvement of techniques/ protocol development for calibration of atmospheric composition instruments > joint development of standards and						> German EUFAR data accessible via IAGOS data portal > improvement of techniques/ protocol development for calibration of atmospheric composition		*(not relevant)*	

		Co-locations									
		ACTRIS	**ARISE**	**EISCAT_3D**	**EUFAR**	**EUROCHAMP**	**HEMERA**	**IAGOS**	**ICOS (Atm)**	**IS-ENES**	**SIOS (Atm)**
		protocols for atmospheric trace species measurements (GHGs, VOCs, NO_x)						instruments, intercalibrations of TGOE measurements & standards (within EUFAR2) > joint development of standards and protocols for atmospheric trace species measurements (GHGs, VOCs, NO_x)			
	EUROCHAMP	> joint research > calibration of instruments in chambers > The communities are merging in 2020, EUROCHAMP chambers will be the exploratory facilities in ACTRIS			> instruments tests in chambers			> instrument tests in chambers	> instrument tests in chambers > using ICOS calibration techniques	*(not relevant)*	
	HEMERA	> connections, e.g., HEMERA data team cooperates with ACTRIS data team > plans of HEMERA to get connections via committees			> collaborations due to personal connections & content-wise/ scientific community overlap (observations in troposphere and in future stratosphere?) > exchange of strategic advisory committee members	> plans to get connect via committees > instrument tests in chambers planned		> HEMERA data team cooperates with IAGOS data team > plans of HEMERA to get connections via committees	> plans to collaborate on GHG measurements	*(not relevant)*	
	IAGOS									*(not relevant)*	

		Co-locations									
		ACTRIS	**ARISE**	**EISCAT_3D**	**EUFAR**	**EUROCHAMP**	**HEMERA**	**IAGOS**	**ICOS (Atm)**	**IS-ENES**	**SIOS (Atm)**
	ICOS (Atmosphere)	Common national RIs and co-location in many countries, Cooperation seeking synergies between Head Offices and Data Centres						> loose coordination meetings > developing common projects and products on European and national (French) level > connections through Advisory Boards		Cooperation on data transfer within EOSCpilot project	Zeppelin Observatory
	IS-ENES								> science demonstrator ERFI in EOSCpilot		*(not relevant)*
	SIOS (Atmosphere)	> SIOS member institutions provide data measured in Svalbard to ACTRIS database							> SIOS member institutions provide data measured in Svalbard to ICOS database		

A.5.2 Collaborations outside ENVRI/ Similar networks outside Europe

The Earth system is highly interlinked and interdisciplinary. For instance, climate science, and by extension atmospheric science, deals with highly complex systems in many different scales ranging from global extent, such as ocean currents, to molecular scales as in formation of aerosols. The complexity calls for thorough information on human activities, biosphere and oceans in addition to the understanding of atmospheric processes. Thus, international collaboration, within the atmospheric domain and beyond, is of utmost importance.

The international landscape of research infrastructures is mapped within the H2020 project RISCAPE (European Research Infrastructures in the International Landscape[35]), with a focus on major European research infrastructures which are listed on the ESFRI roadmap. This report chapter is further linked to the H2020 project COOP+ (Cooperation of Research Infrastructures to address global challenges in the environmental field[36]), which ended in 2018. The goal is to strengthen the links and coordination of EMSO, EISCAT, ICOS, LifeWatch with international counterparts and to leverage international scientific cooperation and data exchange with non-EU countries.

TABLE 10: COLLABORATIONS OUTSIDE THE ENVRI CLUSTER AND SIMILAR NETWORKS GLOBALLY.

RI	Short name	Name	Country/ region	Type of collaboration
ACTRIS	NOAA	National Oceanic and Atmospheric Administration	US	
	MPLNET	The NASA Micro-Pulse Lidar Network	US	
	ARM	Atmospheric Radiation Measurement Climate Research Facility	US	
	ECMWF	European Centre for Medium-Range Weather Forecasts	Europe	Data and services provided to ACTRIS
ARISE	ECMWF	European Centre for Medium-Range Weather Forecasts	Europe	weather prediction, climate modelling
		(collaborations with US groups involved in infrasound studies using large arrays and Russian groups working theoretically)		
	VAACs	Volcanic Ash Advisory centres		Volcanic eruption alerts (ARISE offers complementary observations as it provides permanent

[35] https://blogs.helsinki.fi/riscape-project/, see specifically Deliverable 3.1
[36] www.coop-plus.eu/

RI	Short name	Name	Country/ region	Type of collaboration
				observations of all eruptions)
	ICAO	International Civil Aviation Organization		
	EuroVolc			
	ALOMAR, MAARSY, SKiYMET			New observation techniques of interest for ARISE
EISCAT_3D	AMISR	Advanced Modular Incoherent Scatter Radar	US, Canada	dedicated campaigns, Madrigal as common database, incoherent scatter World Days; COOPEUS project
	MU/EAR	Middle and Upper Atmosphere Radar/ Equatorial Atmosphere Radar	Japan/ Indonesia	
		(Two permanent launch facilities for sounding rockets close to EISCAT_3D stations: Andøya Space Center & Esrange Space Center)	Norway/ Sweden	joint campaigns with rocket flights launched from both facilities
	URSI	International Union of Radio Science		Joint campaigns
	ESA	Space Situational Awareness of the European Space Agency (ESA)		
EUROCHAMP	ICARUS	(chamber network, established in 2017)	US	
EUFAR	ICCAGRA	(coordination committee for airborne geophysical research)	US	Joint organisation of ICARE conference 2017 (and 2020/21)
		(new groups in Romania, Cyprus)		Transfer knowledge
HEMERA	*HEMERA will need collaboration outside the ENVRI cluster in the industrial field for new technologies and with agencies and /or institutions outside Europe for new launch sites (e.g. the Brazilian Space Agency). None of this has been formalised yet.*			

RI	Short name	Name	Country/ region	Type of collaboration
IAGOS	CONTRAIL	Comprehensive Observation Network for Trace Gases by Airliner	Japan	(commercial aircraft for CO_2 routine measurements)
	PGGM	Pacific Greenhouse Gas Monitoring Programme	Taiwan	
ICOS (Atmosphere)	NOAA/ AGAGE	National Oceanic and Atmospheric Administration/	US	Proliferation of WMO Standards for CO_2 and CH_4 produced at NOAA within Europe, International inter-comparison programmes, Cooperation in scientific data evaluation of GHG observations
	NIES	National Institute for Environmental Studies , Center for Global Environmental Research	Japan	Cooperation in scientific data evaluation of GHG observations
	IG^{3}IS	Integrated Global Greenhouse Gas Information System	Global	Scientific approaches to enhance observational capacities
	ECMWF	European Centre for Medium-Range Weather Forecasts	Europe	Common data services to future European GHG verification system
IS-ENES	ESGF	Earth System Grid Federation (DOE, NASA, NOAA, IS-ENES, NCI)	Global	European pillar of ESGF, providing data/ software
	WIP	Working Group on Coupled Modeling Infrastructure Panel	Global	Panel that advices on the international infrastructure for CMIP whuch is driven by the WCRP Working group on coupled modelling
	PRACE	European HPC Infrastructure	Europe	access to supercomputers
SIOS	CHARS	Canadian High Arctic Research Station	Arctic	
	SAON	Sustaining Arctic Observing Networks	Arctic	

RI	Short name	Name	Country/ region	Type of collaboration
	NySMAC	Ny-Ålesund Science Managers Committee	Svalbard	
	SSF	Svalbard Science Forum	Svalbard	

A.6 Gaps (components not covered by RIs)

With the goal to provide data and information for all relevant fields within the atmospheric domain it is important to identify missing components and to check if they could be covered in future by already existing RIs.

General gaps related to ECVs:

- atmospheric electricity/ thunderstorms (However, the ECV 'Lightning', product: Number of lightnings, is measured at some ACTRIS stations. Some EUFAR operators have had involvement in the deployment of electric field measurements from aircraft in order to study cloud electrification. ARISE will support civil applications for monitoring natural hazards including thunderstorms.)

Geographical gaps:

- heterogeneous geographical coverage (main gaps in Mediterranean region incl. Northern Africa and Eastern Europe in many RIs)

RI-specific gaps:

- IAGOS: denser network and more profiles
- SIOS: Atmospheric (as well as practically all) observations in Arctic regions are sparse and uncoordinated. The relations of atmospheric research to other domains should be increased to understand the climate change in a more holistic manner.
- ICOS is planning to fill the gap in continuous observations of atmospheric N_2O concentrations by making N_2O concentration an element of its basic set of measured variables. Filling this gap will help to improve GHG reporting and is related to the H2020 project VERIFY, which aims to develop a system to estimate GHG emissions to support countries' emission reporting to the UN Climate Change Convention Secretariat, for which observations of CO_2, CH_4 and N_2O are essential.
- EUFAR has consistently identified as a gap the lack of European research aircraft with true stratospheric measurement capability (see section A.4). Since this area of interest intersects with HEMERA capability, this might be an area of discussion between EUFAR and HEMERA.

Gap analyses are typically conducted during the community building process of an RI.

- EISCAT_3D: as part of the COOPEUS project a gap analysis with limited scope (focused on data and Europe/ US) (D2.2[37]) and a landscape overview (D2.5[38]) were performed
- HEMERA: gap analyses will be done later in project
- ARISE fills the gap between EISCAT and the other projects dedicated to the study of the lower atmosphere (below 20 km altitude)

[37] www.coopeus.eu/wp-content/uploads/2013/05/GapAnalysis.pdf
[38] www.coopeus.eu/wp-content/uploads/2015/04/D2.5.-COOPEUS_Del2_5_ISR_Roadmap.pdf

EUROCHAMP includes some new chambers, which were built in the last years, filling the gaps which appeared due to new research topics (esp. climate change). The goal is now to increase the level of harmonisation and to increase the usage of chambers.

A.7 User communities

Environmental RIs have become key players in the international research landscape, providing (new) services to support comprehensive research and to promote global integration of the research efforts for a better understanding of environmental systems, and to tackle the Grand Challenges. RIs provide the capabilities and services to produce, collect, archive and provide a comprehensive data basis, and have an important role in training and technological innovation. TNA is a typical form of user engagement of RIs.

SIOS is working towards extended collaborations with the industry in the future. Thereby, SIOS could, e.g., provide the test ground for new scientific equipment in harsh conditions or observational data to the tourist industry, which, in turn, could provide some observations for SIOS.

TABLE 11: USER COMMUNITIES OF THE RIS.

RI	User communities
ACTRIS	Academics
	Weather Services
	Space agencies
	Policy-makers
	Private industry
	Modelling communities
	Operational users
ARISE	Civil, civil security and scientific applications, ECMWF, CTBT related studies; ICAO for remote volcano monitoring
EISCAT-3D	climate and upper-/ mid-atmospheric researchers
EUFAR	Scientific (incl. modelling) community, educational sector, aeronautical industry, space agencies
EUROCHAMP	Scientific (incl. modelling) community, educational sector, general public
	Industrial and commercial sector (innovation: test novel instrumentation and depolluting materials, evaluate atmospheric impact of innovative products)
HEMERA	Scientific (incl. modelling) community, overlaps with the scientific user community of IAGOS, ACTRIS and EUFAR
	Industry? (to test instruments)

RI	User communities
	Remote sensing community (Proof of concept for satellite measurements (tests before start of satellite missions))
IAGOS	Scientific (incl. modelling) community (atmospheric research: process studies, trend analysis)
	Operational users, e.g., Copernicus (CAMS, for model validation), in combination with AMDAR data for weather prediction
	Modelling community (validation of regional and global models, climate and air models)
	Industry
	Remote sensing community (Satellite validation)
ICOS	Scientific (incl. modelling) community
	Operational users, e.g., Copernicus (CAMS)
	Remote sensing community (Satellite validation)
	Data used for IPCC assessments and verification of national inventories
IS-ENES	Climate modelling community, climate research community, community working on impact of climate change, C3S, climate services; Data used for IPCC assessments (CMIP6 will contribute to IPCC 6th Assessment Report)
SIOS	Scientific (incl. modelling) community Remote sensing community (Satellite validation) Public bodies, e.g. environmental agencies Industrial and commercial sector (innovation: test novel instrumentation in harsh conditions and decreases the environmental footprint of observations)

A.8 Portfolio of services and products

The listed portfolio of services is based on a first collection effort. They will be systematically mapped within the ENVRI-FAIR project.

TABLE 12: SERVICES AND PRODUCTS PROVIDED BY THE RIS IN THE ATMOSPHERIC DOMAIN.

RI	Category	Service/ product
ACTRIS	Access	> Physical and remote access in national facilities (observational (fixed ground-based stations delivering long-term data based on a regular schedule and common operation standards) and experimental (atmospheric simulation chambers, laboratory and mobile platforms performing experiments after common standards) platforms) and topical centres: - Research Services - Instrument calibration - Industry services (ACTRIS SOPs and quality guidelines produced at experimental platforms) > Virtual: VRE with tools and computing
	Training/ Education	
	Data products	ACTRIS: data centre with three data repositories (also called topic databases): near surface data (EUSAAR), aerosol profiles (EARLINET) and cloud profiles (CLOUDNET)
ARISE	Data products	- Prototypes for data products from the different networks ➔ calibration with data from experimental campaigns ➔ Preparation of the data products for users - remote monitoring of volcanoes with infrasound IMS network (up to several thousands of km from source, e.g. Etna) ➔ provide alerts ➔ so far prototype ➔ in next project volcanic information system operational - gravity wave data for ECMWF - planning to provide regular data sets/services to operational centres and is working towards data assimilation for weather forecasting (with ECMWF)

RI	Category	Service/ product
		> developing tools for future applications based on the quasi-real-time description of an atmospheric extreme event for civil applications
EISCAT_3D	Training	Training for future engineers
	Data products	(First data expected in 2021; availability of services to be discussed)
EUFAR	Data products	Publicly-accessible database of measurements from in situ airborne measurement campaigns and airborne Earth observation activities
	Access	Access to research aircraft and instrumentation according to user demand, assistance in the planning and conduct of airborne campaigns
	Training/ education	- Knowledge transfer program to share best practice and assist in the development of new facilities and user communities - Open-source software tools for Earth observation imaging products and data quality measures
EUROCHAMP	Access	- Access to chambers through TNA programme, > 16 chambers for diverse research questions, e.g. gas phase chemistry, SOA formation, dust chemistry, ultraclean condition, aerosol aging studies, living bodies exposure, bioaerosol studies, optical properties characterisation, car emission work/ wood burning emission studies/ plant emission work, air-sea exchange, ice-air interface processes - Access to calibration and training facilities
	Instrument testing/ technological development	- Characterisation of new atmospheric monitoring devices - Test of depolluting efficiency of new technologies - Intercomparison of measurement techniques for the atmosphere - Test of secondary pollution from car and plane emissions

RI	Category	Service/ product
		- Elucidation of the atmospheric fate of released compound (e.g., toxics formation) - Evaluation of the atmospheric impact of new emissions (e.g., Global Warming Potential calculation, Photochemical Ozone Creating Potential measurements, atmospheric life time) - Model development and evaluation to enhance and optimally exploit the chamber outputs
	Data products	- virtual access (freely accessible databases and tools, both simulation changer experiments and advanced products) provided by EUROCHAMP Data Centre (since about 10 years, managed by AERIS; 2 pillars of data management (Database of Atmospheric Simulation Chamber Studies (full sets of experiments incl. quality control) + Library of Analytical Resources (reference resources for chemical analysis ➔ level 3 data)) already in previous project (EUROCHAMP2); 3rd pillar soon available: Library of advanced data products (high level products for observation, modelling, radiative transfer calculation ➔ level 3 data), e.g. rate constants, aerosol mass extinction coefficients); EUROCHAMP Data Centre will be integrated into ACTRIS Data Centre - Chemical transport models/ simulating atmospheric chemistry (forecasting air pollution and supporting climate modelling ➔ since about 10 years own work packages for modelling (developed models can be downloaded as elaborated products of EUROCHAMP-2020 in data center)
HEMERA	Access	- Access to stratospheric balloon flights via TNA program, costs for development and construction of payload is not covered; in first phase limited to 150 Z-balloons with 150 kg payload, 15-38 km altitude
	Data products	- Virtual access to data of all measurements during flights (conducted before and during project); set of observations depend on scientific user, instruments for a set of basic parameters will be developed in first phase - first TNA phase comprises three measurement campaigns in summer 2019, summer 2020 and summer 2021 from bases in Kiruna (Sweden) and Timmins (Canada)
	Technology	JRAs to improve ballooning technology and scientific instrumentation
IAGOS	Data products	- Level-4 data as combination of raw data and Lagrangian model output coupled to emission inventories, that provides additional information to users (e.g. CO-contribution)

RI	Category	Service/ product
		- Ancillary data such as ECMWF parameters - back trajectories treated as footprints and clusters - source-receptor link and CO representation error - O_3 and CO from the MACC and CAMS reanalyses are validated with profiles from MOZAIC/IAGOS and from IAGOS-CARIBIC aircraft for the period 2003-2018. Time-series of the difference between model and observations are presented for each available year, along with profiles at individual airports, and the observed climatologies in the UTLS from observations made at cruise altitude - freely accessible data for users in science and policy including air quality forecasting, verification of CO_2 emissions and Kyoto monitoring, numerical weather prediction, and validation of satellite products
ICOS (Atmosphere)	Data products	Level-3 data (e.g. atmospheric inversions): Strong collaboration within the modelling community (e.g. inverse modelling groups in Europe: LSCE, MPI, WUR, LU); e.g. EUROCOM inversion inter-comparison, FLUXCOM/ FluxEngine evaluation of sampling strategies, fossil fuel CO_2 time series (part of RINGO), provision of atmospheric transport footprints/ forward concentration calculations, (inverse) atmospheric transport modelling,
	VREs	Jupyter collaboration tools for scientific analysis
IS-ENES	Access	- Essentially virtual access to software and model data Some TNA for use for use of the coupler software and to access computing service to analyse multi-model data - Training programs, summer schools and workshops - Technology: joint development of the common software and common data and metadata standards as well as the data ESGF infrastructure European pillar of ESGF, providing data/ software
	Other	Infrastructure Optimisation (consulting on how to build an arctic RI)

RI	Category	Service/ product
SIOS (Atmosphere)	Data Hub	Multidisciplinary; no own database, but is harvesting from others; No elaborated data products yet, maybe satellite data products specifically for Svalbard in the future
	Training	Training programs, workshops
	Access	Access, logistics

RIs can also be characterised according to their data life cycle (see ENVRIPLUS D5.1).

Provision of NRT data:

EISCAT_3D is still under construction, but the present EISCAT system provides overview plots of the standard parameters in NRT. ACTRIS, IAGOS and ICOS are delivering NRT data to Copernicus (see section A.3.2).

EUROCHAMP, HEMERA, ARISE, SIOS, EUFAR and IS-ENES are not providing any NRT data. The data provided by EUROCHAMP is the result of experiments performed in simulation chambers, i.e. the data needs to be processed before being shared. In case of HEMERA, the observations depend on the user, whereby NRT data provision is not planned. ARISE data are too complex to be provided in NRT, but the data gathered during the project duration is openly available. Nevertheless, for civil applications ARISE is developing tools for future applications based on the quasi-real-time description of an atmospheric extreme event. An example is the remote monitoring of volcanoes. EUFAR does not collect and provide the data of the campaigns except metadata, and SIOS harvests data from other data bases. IS-ENES does not have own observations which could be provided in NRT.

A.9 Citizen science experience

Citizen Science describes the involvement of members of the public in scientific research, e.g., for creation of research questions, data collection and analysis, or volunteer computing. Principles for Citizen Science are provided, e.g., by the European Citizen Science Association[39]. The potential and added value of Citizen Science depends on the field and is increasingly discussed in research and innovation policy. Environmental science is among the most favourable fields to conduct Citizen Science due to the general interest of the public in environmental topics. In turn, getting the public involved raises the awareness on environmental problems. The inclusion of Citizen Science as tool in environmental RIs could have great potential, not only in ecological and biodiversity research as mentioned in the ESFRI Roadmap 2018 and already applied by LifeWatch ERIC, but, for instance, for spatially and/ or temporally dense atmospheric long-term observations or sampling in remote areas. In turn, RIs could represent suitable formal support structures for Citizen Science, which are not sufficiently developed yet.

RIs in the atmospheric domain have only very few Citizen Science experiences. HEMERA offers flight opportunities for schools and higher education institutions. Their projects sometimes qualify for the term Citizen Science. In a broader sense IAGOS conducts Citizen Science by measuring onboard commercial aircrafts provided for free by airlines. Thereby, the airlines are the members of the public being involved in the science, whereas the aircraft passengers might not even know about the measurements.

A.10 National memberships in RIs

The national participation in RIs differs strongly between the European countries. Several countries, including France, Germany, UK and Spain, are involved in one way or another in all or at least most RIs included in this analysis. It is evident that the participation of, particularly, small countries and countries in South-Eastern and Eastern Europe is lower, which might reflect the differences in the funding capacity, especially for research. Environmental RIs are not always in the focus of national RI roadmaps of countries having limited financial means (e.g., Baltic States). In addition, the participation of a country in an RI might be hindered or delayed by the national roadmap processes if they exist, as they are related to the political commitment and financial support (from national sources) needed.

[39] https://ecsa.citizen-science.net/sites/default/files/ecsa_ten_principles_of_citizen_science.pdf

Most European countries have already a national roadmap for RIs or are preparing one. Their development is not mandatory but encouraged by the European Commission, as ESFRI orients on the prioritisation of RIs within the national roadmaps. The national roadmaps should be aligned to the National European Research Area (ERA) Roadmap, which is in turn mandatory. National roadmaps follow different approaches and goals, and their importance varies between countries. The H2020 project InRoad[40] gives recommendations to harmonise and synchronise the national roadmap processes within Europe, including priority-setting, funding and lifecycle management of Research Infrastructures, by exchanging best practices among the main stakeholders of EU Member States, Associated Countries and at European level.

The most recent versions of half of the national roadmaps (total n=25) are older than 4 years (2014 and earlier). In most countries, the national roadmaps are revised every four to six years and their development is detached from the ESFRI roadmap process and not harmonised in terms of procedures, rules and budget thresholds (see Deliverable 12.3, Kutsch et al., 2018), which would, however, be very beneficial. For several countries a revision is due (e.g., Poland, Romania, UK). National roadmaps often focus on national RIs and the participation in those pan-European RIs, that are ESFRI Projects or Landmarks. The national participation is of particular interest for those RIs providing a network of distributed long-term observations and aiming for pan-European spatial coverage, particularly, ICOS and eLTER.

The UK is currently developing a national integrated concept for atmospheric research. In Finland and Czech Republic the participation in pan-European RIs in the atmosphere and terrestrial ecosystem domains is coordinated by national RIs, namely INAR RI (Institute for Atmospheric and Earth System Research-Infrastructure) and CzechGlobe – the Global Change Research Institute of the Czech Academy of Sciences (GCRI), respectively. Thereby, Czechglobe is a European center of excellence investigating the ongoing global change and its impact on the atmosphere, biosphere and human society. Czechglobe coordinates the Czech participation in ICOS (Integrated Carbon Observation System, three ecosystem stations and one atmosphere station), and ACTRIS (one observatory co-located to the ICOS atmosphere station). The coordination of the Czech participation in AnaEE, eLTER RI, and DANUBIUS is foreseen. Czechglobe furthermore undertakes research in environmental metabolomics and remote sensing of processes within carbon and other biogeochemical cycles (aircraft and hyperspectral sensors, EUFAR). In a similar approach, INAR RI (see Bäck et al., 2017) represents the umbrella for the Finnish participation in ESFRI-listed RIs of the environmental domain, focusing on atmosphere, biosphere and their interactions. It aligns the Finnish activities in ICOS, ACTRIS, AnaEE and eLTER RI towards common targets to facilitate efficiency in the observations and avoid duplication of effort. Finland is the host country of ICOS ERIC and the ACTRIS-PPP.

The Netherlands have pooled their atmospheric research in an integrated program called ‘Skies over Holland’ providing infrastructure for a combined model-observations system, the Ruisdael Observatory. It will be the Dutch contribution to ICOS (atmosphere) and ACTRIS.

[40] for the results see www.inroad.eu (Publications)

TABLE 13: NATIONAL PARTICIPATION/ NATIONAL INSTITUTES INVOLVED IN DIFFERENT RIS (AS OF 24 JANUARY 2019), HOST' MEANS THAT THE COORDINATING INSTITUTE IS IN THE RESPECTIVE COUNTRY. NON-EU-28 COUNTRIES WITHOUT ANY PARTICIPATION ARE NOT LISTED HERE.

Country	Year(s) of publication	Mentioned in national roadmap	ACTRIS	ARISE	EISCAT_3D	EUFAR	EURO-CHAMP 2020	HEMERA	IAGOS	ICOS	IS-ENES	SIOS
EU-28 members												
Austria	2014					x4						
Belgium	Under preparation		x1, x2, x3			x (host), x3, x4	1			**x**, @		
Bulgaria	2010, 2017	ACTRIS	x1, x2, x3									
Croatia	2014											
Cyprus	Under preparation		x2, x3									
Czech Republic	2010, 2015	ACTRIS, EUFAR, ICOS	x1, x2, l2, x3, l3	x		x, x3, x4				**x,** @	x3	
Denmark	2011, 2015	ICOS	x2				2			**x**, @	x2	
Estonia	2014		x2							h		
Finland	2014	ACTRIS, EISCAT_3D, ICOS, SIOS	x1, x2 (host), x3		x, @	x2, x3	3			**x** (host), @	x1	x

France	2008, 2012, 2016	ACTRIS, EISCAT_3D, EUFAR, IAGOS, ICOS, IS-ENES (as CliMERI-FR)	x1, x2, l2, x3, l3	x (host)	a	x, x1, x2, x3, x4 (adminis-trative coord.)	1, 2, 3 (current host)	x (host)	x (host)	**x**, @	x1, x2, x3 (each time host)	x
Germany	2013	IAGOS, ICOS	x1, x2, x3	x		x, x1, x2, x3, x4	1, 2, 3 (former host)	x	x	**x**, @	x1, x2, x3	x
Greece	2014	ACTRIS, ICOS	x1, x2, x3				x			h	x1, x3	
Hungary	2018	ACTRIS, ICOS	x1, x3			x3				h		
Ireland	2007		x1, x2, x3	x		x2	1, 2, 3			p, h		
Italy	2011, 2017*	ACTRIS, ICOS	x1, x2, x3 (host)	x		x2, x3, x4	3	x		**x**, @	x1, x2, x3	x
Latvia	-											
Lithuania	2011, 2015											
Luxembourg	-											
Malta	-											
Poland	2014*	ICOS	x1, x2, l2, x3, l3			x, x3, x4				p, h		x

Portugal	2014	ICOS		x						p, h		
Romania	2008		x1, x2, x3	x		x2	3			h	x1, x2	
Slovakia	-											
Slovenia	2011, 2016											
Spain	2013		x1, x2, l2, x3, l3			x1, x2, x3, x4	1, 2, 3			p, h	x1, x2, x3	
Sweden	2015	ACTRIS, EISCAT_3D, ICOS, SIOS	x1, x2, x3	x	X (host), @	x2	1, 2	x		**x**, @	x1, x2, x3	x
The Netherlands	2008, 2013, 2016	ACTRIS, ICOS	x1, x2, l2, x3, l3	x		x2, x3				**x**, @	x1, x2, x3	x
The United Kingdom	2010, 2012	EISCAT_3D, ICOS	x1, x2, x3, l3	x	x	x, x1, x2, x3, x4 (scientific coord.)	1, 2, 3	x	x	**x**, @	x1, x2, x3	x
Non-EU-28 members												
Belarus	-		x1, x3									
Iceland	-			x								
Montenegro	2015											
Norway	2012, 2016	EISCAT_3D, ICOS, IS-ENES (as 'E-	x1, x2, x3	x	x, @			x		**x**, @	x2, x3	x (host)

		INFRA'), SIOS										
Serbia	-										x3	
Switzerland	2015	EUFAR, ICOS	x1, x2, x3	x		x2, x3, x4	1, 2, 3			**o**, @		
Ukraine	-				a							

*Roadmap not available in English

Legend:

x = Full member/ in consortium (bold = ERIC member)
o = Observer (bold = ERIC member)
a = Affiliated country
p = Partner in PP project (but not in ERIC, if appropriate)
l = Linked third party
@ = countries with stations

ACTRIS: *x1 = partner in* ACTRIS I3 (2011-2015), x2 = beneficiary in ACTRIS PPP (2017-2019), l2 = linked third parties in ACTRIS PPP, x3 = partner in ACTRIS-2 (2015-2019), l3 = linked third parties in ACTRIS-2

ARISE: + Israel, Ivory Coast, Madagascar, Tunisia

EISCAT_3D: + Japan, China (as full members), South Korea (as affiliated country)

EUFAR: x = in AISBL, x1 = 1st project 2000-2004, x2 = 2nd project 2004-2008 (in addition: Israel), x3 = 3rd project 2008-2013 (+ Israel), x4 = 4th project 2014-2018 (+ Israel),

EUROCHAMP: x1 = EUROCHAMP (2004-2009), x2 = EUROCHAMP-2 (2009-2013), x3 = EUROCHAMP-2020 (2016-2020)

HEMERA: + Canada

ICOS: h = Participation in a H2020 INFRADEV project RINGO (2017-2020) as country potentially joining the ERIC; @ = hosting an ICOS atmospheric station

IS-ENES: x1 = IS-ENES (2009-2013), x2 = IS-ENES2 (2013-2017, in addition: South Africa), x3 = IS-ENES3 (2019-2022)

SIOS: + Japan

A.11 Data interoperability

Data interoperability is key for interdisciplinary collaboration and an efficient use of diverse data in order to address the grand environmental challenges. Complete data interoperability consists of schematic[41], syntactic[42] and semantic[43] interoperability[44]. Each RI is working on its internal data interoperability, e.g., by introducing metadata standards. Particularly for networks of experimental platforms and focusing on physical access, for which standardisation of measurements is limited, it is of utmost importance to have thorough and standardised metadata to make sure that the data produced can be understood and used by others.

For instance, observational data gathered in EUFAR are not standardised completely, as the partner institutes are normally collaborating with national metrology centres and the data is not centrally managed by EUFAR. However, although it has only very few resources for data management, EUFAR makes sure that the observational data is easily discoverable and accessible, and provides thorough metadata for the campaigns and measurements, and is currently developing respective standards.

Whereas schematic and syntactic interoperability are technological matters that are relatively easy to solve, semantic interoperability is seen as a major challenge. Nevertheless, in case of RIs integrating different communities/ networks such as ARISE even an agreement, e.g., on common data formats can be difficult, but is important for syntactic interoperability. Data interoperability between the networks and the ARISE data portal is planned to be addressed in the ARISE3 project.

Semantic interoperability paves the way for accurate and reliable communication and exchange. It requires agreement on common ontologies, vocabularies, metadata standards and frameworks such as Essential Variables. WMO GAW provides a common terminology and SOPs for many atmospheric observations, which are defined as core variables in the six focal areas and (expected to be) used by the RIs for respective observations. For observations not covered by WMO GAW standards, SOPs are developed as community efforts (e.g. within AERONET, a federation of ground-based remote sensing aerosol networks). Observational data of the RIs are compatible with WIS (as single coordinated global infrastructure responsible for the telecommunications and data management functions), GEOSS and INSPIRE (Infrastructure for spatial Information in Europe).

The ENVRI community has a strong interest to improve the (data) interoperability between the different RIs in order to simplify future collaborations. The ENVRI Reference Model, which was developed and further improved within the EU projects ENVRI and ENVRIPLUS, serves as a community standard to help the RIs achieve better interoperability between their heterogeneous resources, particularly with regard to data and services. The ENVRI Reference Model is originally based on the experience gathered by several research infrastructures. It is particularly helpful for those that are in the planning/construction phase.

[41] Schematic interoperability defines the structure (schema, i.e. common classifications and hierarchical structures) in which the data will be offered by a service.
[42] Syntactic interoperability defines the way in which data services will be invoked, i.e. the structure or format of data exchange, and is achieved through tools such as XML or SQL Standards.
[43] Semantic interoperability defines accurate and reliable communication which is gained by is gained by a common vocabulary.
[44] See www.earthobservations.org/documents/geo_xii/GEO-XII_10_Data%20Management%20Principles%20Implementation%20Guidelines.pdf

Still remaining challenges related to data interoperability (between the RIs and beyond) are addressed within the H2020 project ENVRI-FAIR running 2019-2022[45]. However, only ESFRI-listed RIs and SIOS (which was still on the ESFRI roadmap during the proposal) are participating in the project, excluding all other RIs even though for them data interoperability is no less important, including IS-ENES, which is as a modelling RI strongly dependent on observational data and respective FAIR principles and has already expertise on FAIR data for climate model results.

ENVRI-FAIR is the second-biggest cluster project in the EU-call for EOSC. Its overarching goal is the implementation of FAIR (Findable, Accessible, Interoperable, Re-usable) data principles in the ENVRI cluster (on cluster level, domain level and RI level) and its connection to the EOSC. This goal will be reached by (1) well defined community policies and standards at all steps of the data life cycle, aligned with the wider European policies, as well as with international developments; (2) sustainable, transparent and auditable data services of the participating RIs, for each step of data life cycle, compliant to the FAIR principles; (3) a focus on the implementation of prototypes for testing pre-production services at each RI (the catalogue of prepared services is defined for each RI independently, depending on the maturity of the involved RIs); and (4) exposure of the complete set of thematic data services and tools provided by the ENVRI cluster under the EOSC catalogue of services via the EOSC-hub. As part of the project, the landscape is mapped with regard to, e.g., existing data policies. The main focus lies on implementation and further development of services at RI and domain levels, while ensuring the highest possible level of standardisation for each domain. In the project the technical preconditions will be established for the implementation of a virtual, federated machine-to-machine interface to access environmental data and services (service point) provided by the contributing ENVRIs, called the ENVRI-hub.

B. Implications for future collaboration and further integration

This section is meant to identify potentials for increased collaboration and integration in order to address the Grand Challenges jointly and thus more effectively. While each RI addresses individual scientific questions, combining the expertise and output provided by the RIs allows to answer scientific questions which are beyond the capabilities of the single RIs, e.g., by combining observations at different altitudes. The further identification of gaps will also provide an important contribution to identifying potential joint research topics in the future.

B.1 Potentials for joint research topics

During the interviews the following potential joint topics were identified:

- Air pollution composition and monitoring (EUROCHAMP)
- Impact from solar activity and space weather events on the atmosphere/biosphere (EISCAT_3D)
- The use of chemical tracers to further understand processes of exchange between the surface layer, the planetary boundary layer and the lower part of the troposphere (strong need for vertical profiles) (IAGOS, EUROCHAMP)
- The characterization of global air pollution trends of reactive trace gases (ozone, reactive nitrogen gases, VOCs, …) and aerosols, as well as trends of long-lived greenhouse gases (CO_2, CH_4) (IAGOS)

[45] An analysis of the data interoperability of the RIs involved in ENVRI-FAIR is provided within ACTRIS-2 WP5 (Deliverable 5.4): www.actris.eu/Portals/46/Documentation/actris2/Deliverables/public/WP5_D5.4_M49.pdf?ver=2018-06-07-094718-377.

- The investigation of emissions, long-range transport and chemical transformation processes also known as source-receptor link (strong need for service developments) (IAGOS, EUROCHAMP)
- Explore where further atmospheric observations outside Europe could be supported (responsibility of Europe mentioned in ESFRI roadmap), but the respective local stakeholders need to be involved in the planning from the beginning.
- Combining observations at different altitudes: HEMERA is looking forward to collaborations and could contribute measurements of trace gases, aerosols, clouds for chemical and also dynamical questions where altitude coverage up to the stratosphere is required (complementary to ground stations and satellites).
- Explore links to other fields, e.g., Energy and Health and Food: Currently links to Health and Food community (Copernicus General Assembly, WHO, WMO) are discussed in IAGOS. They are a matter of resources so far. IAGOS is not actively involved in projects of the Health and Food field, but provides data. Possibly, the Health and Food field could be approached jointly with ACTRIS.
- Exchange of experience with citizen science
- Technological innovation:
    - Common investments in development of new instruments (new variables or new methods to facilitate a broader use at lower cost)
    - ARISE has plans to develop the prototype of a LIDAR (for measurements of temperature and wind) to cover the altitudes 30-50 km where measurements are missing and where the ECMWF model has problems

B.2 Potentials for joint fit-for-purpose services and products

The goal is to further develop the output of the RIs from separately providing access to facilities and research data towards synergetic products and services.

- Validation of satellite data and model forecasts: There is a strong need of NRT to Real Real-Time (RRT) data delivery. (IAGOS)
- Coordination of HEMERA balloon flights with activities of other RIs (e.g., EUFAR, IAGOS, ACTRIS)
- Services providing the source-receptor link for data or any information on the origin of the air masses sampled by the instruments (IAGOS)
- Facilities to build “level 3” data on-line on user requests (specific averages, specific gridded data for model evaluations) (IAGOS)
- Co-location of tools for satellite validation (IAGOS)
- Production of “environment” data sets to locate the individual measurements into a broader perspective (spatial, temporal) thanks to satellite and/or model outputs (IAGOS)
- “System of alert” with automatic detection of anomalies (IAGOS)
- Address the challenges and requirements of the Copernicus Services[46]; ACTRIS, IAGOS and ICOS will significantly enhance the products and the kind of data submitted to Copernicus in the next 2-4 years), e.g. CAMS in situ component challenges:
    - More information on aerosol size distribution is needed and is lacking from standard observation networks.
    - More vertical profile information on all components would help to improve the model evaluation and assimilation
    - As a good indication for the quality of the predictions, model analyses and forecasts are compared to in situ observations as close to real-time as feasible. For data assimilation purposes data should be available within 5 hours and for validation purposes within a week.

[46] http://eurogoos.eu/download/project_deliverables/Copernicus-2017-and-Research-Infrastructures.pdf; https://insitu.copernicus.eu/library/reports/WorkshopDocumentEvolutionoftheCopernicusInSituComponentWorkshop25April2018Final.pdf

  - Harmonised and standardised metadata
- Potential joint proposals: Copernicus

B.3 Potentials for co-location of sites

Site co-location has already been achieved or is currently taken into account between ICOS and ACTRIS in Finland, Sweden, Germany, Italy, Norway and Czech Republic. Further potential will be explored also for cross-domain co-location. Common sites usually save costs for construction and maintenance of the basic infrastructure and often also facilitates the development of cross-RI scientific cooperation.

B.4 Recommendations for future collaboration and implications on governance

The ENVRI community has provided the ENVRI sustainability plan (ENVRIPLUS Deliverable 17.5) and ENVRI strategy (ENVRIPLUS Deliverable 17.2). Both documents were discussed in BEERi, where a common direction of the ENVRI cluster towards a consortium agreement and a coordinated funding and communication strategy was agreed and started. This document – together with deliverable 12.3 – also supports the further development of the domain and as such builds a triangle of viewpoints towards future collaboration among the ENVRIs. From the viewpoint of this analysis, the following measures are important:

- Get data interoperability operational, instead of being just demonstrated in pilots.
- One-stop-shop for all RIs practically not realisable (huge amounts of data, too different data types, it will take the user forever to find something), rather linkage to different data repositories through respective data portals (per RI (see, e.g., ACTRIS) or per altitude range?)
- Start intense collaboration immediately and before being 100 % operational. This will avoid potential reconfiguration later on.
- Check which RIs could work together to minimize conflicts for site PIs which RI they will join.
- Avoid competition for country contributions by developing incentives for countries participation in multiple RIs.
- Exchange and transfer knowledge to countries which are less experienced with regard to RIs.
- Intensive exchange on results of ENVRI-FAIR (e.g., in BEERi), which is restricted to ESFRI-listed RIs and SIOS, to increase FAIRness also in other RIs.

References

Krishnamoorthy, S., Komjathy, A., Pauken, M. T., et al., 2018: Detection of artificially generated seismic signals using balloon-borne infrasound sensors. Geophysical Research Letters, 45(8), 3393-3403.

Kutsch, W., Mirtl, M., Roy, J., Santamaría Ulecia, J. M., Bäck, J., Haubold, H.,and Chabbi, A., 2017: Further integration of research infrastructures related to terrestrial ecosystem research including recommendations on co-locating research sites on national and international level. ENVRIPLUS Deliverable 12.3, available at: www.envriplus.eu/wp-content/uploads/2015/08/D12.3-.pdf

Asmi, A., Konijn,J. and Pursula,A., 2014: ERIS – Environmental Research Infrastructures Strategy for 2030. available at: www.project.envri.eu/documents/10995/ERIS.pdf

Appendix

A – List of interview partners

Interviews were conducted with the following core people of the RIs:

RI	Name
ACTRIS	Sanna Sorvari Sundet
ARISE	Elisabeth Blanc
EISCAT_3D	Anders Tjulin
	Ingemar Häggström
EUFAR	Phil Brown
EUROCHAMP	Jean-Francois Doussin
	Matilde Oliveri
HEMERA	Felix Friedl-Vallon
IAGOS	Valerie Thouret
ICOS (Atmosphere)	Leonard Rivier
IS-ENES	Sylvie Joussaume
	Francesca Guglielmo
SIOS	Heikki Lihavainen

We further acknowledge Rigel Kivi (Finnish Meteorological Institute) and Wim Hugo (SAEON) for their availability for discussion.

B – List of variables observed by ACTRIS

Remote sensing	In situ
Aerosols	
Attenuated backscatter profile	Particle light scattering and backscattering coefficients
Volume depolarization profile	Particle number size distribution - mobility diameter
Particle backscatter coefficient profile	Particle number size distribution - optical and aerodynamic diameter
Particle extinction coefficient profile	Particle light absorption coefficient and equivalent black carbon concentration
Lidar ratio profile	Particle number concentration
Ångström exponent profile	Nanoparticle number size distribution
Backscatter-related Ångström exponent profile	Nanoparticle number concentration
Particle depolarization ratio profile	Cloud condensation nuclei number concentration

Particle layer geometrical properties (height and thickness)	Mass concentration of particulate organic and elemental carbon
Particle layer optical properties (extinction, backscatter, lidar ratio, Ångström exponent, depolarization ratio, optical depth)	Mass concentration of particulate organic tracers
Column integrated exctinction	Mass concentration of non-refractory particulate organics and inorganics
Planetary boundary layer height	Mass concentration of particulate elements
Spectral Downward Sky Radiances	
Direct Sun/Moon Extinction Aerosol Optical Depth (column)	

Trace gases	
Ozone profile	NMHCs
Ozone partial columns	OVOCs
Ozone column	Terpenes
Formaldehyde column	NO
Formaldehyde lower tropospheric profile	NO_2
NO_2 column	Condensable vapors
NO_2 partial columns	
NO_2 lower tropospheric profile	
NH_3 column	
C_2H_6 column	

Cloud (profile)	
Radar reflectivity factor	Liquid Water Content
Radar Doppler velocity	Droplet effective diameter
Radar Doppler spectral width	Droplet number concentration
Radar linear depolarisation ratio	Droplet size distribution
Attenuated backscatter profile	Interstitial particle number concentration
Cloud/aerosol target classification	Interstitial particle size distribution
Drizzle drop size distribution	Total particle number concentration
Drizzle water content	Total particle size distribution
Drizzle water flux	Cloud residuals number concentration
Ice water content	Cloud residuals composition
Liquid water content	Ice particle number concentration
Dissipation rate of TKE (turbulent kinetic energy)	Ice particle size distribution
Atmospheric boundary layer classification	Ice nucleating particle number concentration
Liquid water path	Ice nucleating particle temperature spectrum
Temperature profile	Bulk cloud water chemical composition
Relative humidity profile	
Integrated water vapor path	

C – Overview on the ARISE station network.

Observation stations	Instrument	Measured parameters	Altitude range	Resolution in altitude and time	Observation periods	Comments/ Applications
ALOMAR reference station	RMR lidar	Temperature and zonal, meridional wind	30-85 km	1km, 1hour	Day and night,campaigns	Full high resolution profiles for case studies and model validations (GW, tides) Polar regions
	Meteor radar	Zonal wind	80-100 km			
	Fe lidar	Temperature	80-95km			
OHP and Maïdo reference stations	RMR lidar	Temperature and zonal wind	25-90 km (temperature)	1 km, 1 hour	Night-time, during campaigns	High resolution profiles for case studies and model validations (GW) Mid latitude and tropics
			5-50 km (wind)			
NDACC network	RMR lidars	Temperature	25-90 km	One mean profile per night	Night-time, 3 days per week, operational	Stratospheric climatology, SSW, trends
CTBT IMS Infrasound network	infrasound mini arrays	Gravity waves	Ground based observations	Less than 1 min	Continuously	Extreme event monitoring GW climatology at global scale
Selected infrasound station	Infrasound mini array	Effective sound speed	30-90 km	1 km, 1 hour	Repetitive infrasound sources needed	Stratospheric climatology, SSW
Trondheim station	Meteor radar	Horizontal wind	80-100 km	3km, 1 hour	Continuously, operational	Mesospheric climatology (GW, tides) and case studies
Prototypes/ campaigns	WIRA (campaigns in the reference stations)	zonal, meridional wind	30-75 km	Typically 10-12km, 6-12 hours	Quasi continuously; tests during campaigns	Wind background; continuity in observations in complement to lidars
	CORAL lidar (IMS I26 station, Argentina)	Temperature	30-78 km	1 km, 5 min	Night-time; tests during campaigns	Mobile automatic high resolution lidar; infrasound-lidar synergy

D – List of atmospheric simulation chambers coordinated by EUROCHAMP

Name: CESAM

Location: Paris, France

Coordinates: 48.788468, 2.445422

Specific focus: The CESAM chamber has been designed to perform realistic conditions experiments involving several phases like organic particles, water droplets, mineral dust, soot, salt and gas phase. It is an atmospheric simulation chamber dedicated to the study of multiphase atmospheric processes such as the formation of secondary aerosol or gaseous compounds in cloud-phase reactivity.

Name: HELIOS

Location: Orléans, France

Coordinates: 47.836818, 1.942056

Specific focus: HELIOS is a large hemispherical outdoor simulation chamber (volume of 90 m3) positioned on the top of ICARE-CNRS building in Orléans.HELIOS is dedicated mainly to the investigation of the gas phase processes and radical chemistry under different conditions (sunlight, artificial light and dark). It is equipped with a large set of instrumentation: in situ FTIR (up to 500 m path length), PTR-ToF-MS (Ionicon 8000), Aerodyne ToF-CIMS, ATD-GC-MS, UHPLC, IC, SMPS, Lopap, HCHO (Aerolaser), Spectroradiometer, Monitors (O3 and NOx),…. Other instruments for radicals' measurements are under development (FAGE for HOx and CRDS for NO3).

Name: ISAC

Location: Lyon, France

Coordinates: 45.780758, 4.875624

Specific focus: ISAC is a medium sized indoor simulation chamber which has been developed specifically to investigate interfaces processes such as air-water-air, air-sol interfaces. It is made of a 2m3 Teflon envelop embedded in a structure containing the irradiation system UV and visible light sources. On the floor of the chamber sits a tank which can be filled with any liquid/material/chemicals. The liquid filling and emptying can be done without opening the chamber. The cuboid shape of the chamber allows people to enter by a door to manually scrub the walls and the tank allowing to minimize the memory effects of the chamber.

Name: QUAREC

Location: Wuppertal, Germany

Coordinates: 51.244961, 7.149383

Specific focus: The QUAREC reactor consists of two quartz cylinders with an inner diameter of 0.47 m and a total joined length of 6.2 m.The chamber is closed at both ends by aluminium flanges which contain numerous inlet and outlet ports. The reactor can be evacuated to 10-3mbar by a turbo molecular pump system.

The photolysis system consists of 32 superactinic lamps (Philips TL05 40W,l= 300-480 nm withlmax= 360 nm) and 32 low pressure mercury lamps (Philips TUV,l= 254 nm). The lamps are wired in parallel thus allowing a large variation in the photolysis frequencies/radical levels within the chamber.

Name: AIDA

Location: Karlsruhe, Germany

Coordinates: 49.011878, 8.416859

Specific focus: The AIDA facility comprises the large 84.5 m3 volume aluminium aerosol and cloud simulation chamber AIDA connected to a 3.7 m3 volume stainless steel aerosol preparation and characterisation chamber. AIDA allows aerosol and cloud experiments within a wide range of temperature (+50°C to -90°C), pressure (1 to 1000 hPa), relative humidity (0% to 100%), and on time scales of minutes to several days. During cloud simulation experiments, transient water and ice supersaturations are achieved for time periods from minutes up to about 1 hour with peak relative humidity values of more than 200%. The AIDA facility is equipped with an extensive suite of state of the art instruments, both commercial and custom built. Research areas supported at the ADIA facility include aerosol physics, aerosol chemistry, and aerosol-cloud interactions.

Name: LEAK-LACIS

Location: Leipzig, Germany

Coordinates: 51.352666, 12.434550

Specific focus: The simulation chamber LEAK has a cylindrical geometry and a volume of 19 m3. Main focus of the performed work is on SOA formation and particulate products. LEAK experiments are

performed at humidities up to 80%, allowing the study of multiphase chemical processes with deliquescent particles. The Leipzig Biomass Burning Facility (LBBF) is part of LEAK. This facility allows studying not only the emissions from biomass burning but also the processing (aging) of the emitted smoke. The Leipzig Aerosol and Cloud Interaction Simulator (LACIS) is a world-widely unique infrastructure for investigating aerosol-cloud-interaction processes under well-defined fluid- and thermodynamic conditions.

Name: CHAMBRe

Location: Genoa, Italy

Coordinates: 44.415380, 8.926601

Specific focus: ChAMBRe (Chamber for Aerosol Modelling and Bio-aerosol Research) is stainless steel atmospheric simulation chamber (volume approximately 3 m3) installed at the National Institute of Nuclear Physics in Genoa (INFN-Genova, www.ge.infn.it) and developed in collaboration with the Environmental Physics Laboratory at the Physics Department of Genoa University.

Name: SAPHIR

Location: Jülich, Germany

Coordinates: 50.917044, 6.404878

Specific focus: SAPHIR provides a platform for reproducible studies of the atmospheric degradation of biogenic and anthropogenic trace gases and the build-up of secondary particles and pollutants.The high purity of the air supply and the large volume to surface ratio allows running experiments at low, atmospheric concentrations of trace gases with only minor influences of chamber wall interactions, so that the transformation of trace gases and aerosol can be observed over a long period up to several days. The SAPHIR chamber is equipped with a comprehensive, unique set of sensitive instruments for radicals, traces gases, aerosols, and physical parameters.

Name: EUPHORE

Location: Valencia, Spain

Coordinates: 39.551577, -0.461862

Specific focus: EUPHORE is one of the major international outdoor simulation chamber facilities and it is used to research atmospheric chemical processes. Its characteristics allow the simulation of these processes under near-real conditions thanks to its large size and to the use of natural light. The installation has two twin outdoor atmospheric simulation chambers. Each chamber consists of a half spherical transparent bag of fluorine-ethene-propene (FEP) with a volume of about 200 m3, making it one of the biggest outdoor simulation chambers in the world. EUPHORE chambers are equipped with a large number of analytical instruments for measuring physical parameters as well as a diverse range of biogenic and anthropogenic compounds and its intermediates and products in both the gas and the particle phases.

Name: PACS-C3

Location: Villigen, Switzerland

Coordinates: 47.538797, 8.229908

Specific focus: PACS-C3 consists of 3 different simulation chambers, a stationary 27 m3 chamber (air-conditioned at 15 to 30°C), a mobile 9 m3 chamber (without own air condition), and a stationary 9 m3 cool chamber (air-conditioned at 10 to 30°C).The stationary big chamber has the advantage of a air volume which is important when many instruments sample for long times, such as for intercomparison purposes. The mobile chamber can be brought to any emission source and is therefore especially suited to e.g. evaluate secondary organic aerosol (SOA) formation from test benches. The cool chamber is able to simulate SOA formation also at temperatures below 0°C, which is especially relevant for wood burning emissions, which typically occur at low temperatures.

Name: IASC

Location: Cork, Ireland

Coordinates: 51.892330, -8.493253

Specific focus: The Irish Atmospheric Simulation chamber (IASC) Facility is a large (27 m3) indoor reactor for studies of atmospheric processes. It is equipped with a full range of instrumentation, including a unique custom-built spectroscopy system for in situ measurements of gases, radicals and particles. Areas of scientific expertise include; VOC oxidation, SOA formation and characterisation, development of spectroscopic techniques, evaluation of new instruments, sensors and associated technologies.

Name: ILMARI

Location: Kuopio, Finland

Coordinates: 62.603756, 29.744203

Specific focus: ILMARI facility is a unique and top class laboratory facility bringing together combustion emission studies, atmospheric aging processes and health related toxicological studies. The real life combustion appliances and also real plants are connected to atmospheric simulation chamber enabling the simulation of atmospheric particle formation and aging processes of the exhaust in realistic conditions. The highly controlled in-vitro studies using on-line cell exposure unit and subsequent toxicological analysis allows the investigation of activated cellular mechanisms related to adverse aerosol health effects.

Name: ESC-Q-UAIC

Location: Iasi, Romania

Coordinates: 47.175205, 27.574066

Specific focus: The environmental simulation chamber (ESC-Q-UAIC), from the “Alexandru Ioan Cuza” University of Iasi (UAIC), consists of three quartz tubes connected by flanges with a total length of 4.2 m, has an inner diameter of 0.48 m and a volume of about 780 L. Sampling lines are appropriately disposed for on-line/off-line measurements of various chemical parameters (gaseous or aerosol phase products). Both actinic and black-light lamps, evenly spaced around the reaction vessel, can be used to undertake photolysis processes under simulated solar light condition.

Name: FORTH-ASC

Location: Patras, Greece

Coordinates: 38.334406, 21.819311

Specific focus: FORTH-SC is an indoor smog chamber. It is made of a10-15 m3 Teflon reactor in a 30 m3 temperature controlled UV-equipped room.Instrumentation includes: HR-AMS, PTR-MS, SMPS, Ultrafine-SMPS, APS, thermodenuder, SO2, NOx, CO, CO2, O3, NH3 monitors, MAAP, TEOM, nephelometer, Dry-Ambient Aerosol Size Spectrometer (DAASS).Its unique feature consists of its source characterization (wood burning, open burning, gasoline and diesel engines, scooters, food cooking, etc.)

Name: HIRAC

Location: Leeds, UK

Coordinates: 53.806719, -1.555237

Specific focus: HIRAC is a stainless steel, 2 m3 cylindrical simulation chamber equipped with a variety of instrumentation to monitor both radicals and stable species. The focus of HIRAC is on gas phase chemistry.

Name: MAC-MICC

Location: Manchester, UK

Coordinates: 53.467167, -2.233804

Specific focus: The infrastructure comprises a pair of coupled chambers within the Centre of Atmospheric Sciences (CAS), at the University of Manchester that may be accessed together or as separate installations. The Manchester aerosol chamber (MAC) has been designed to study atmospheric processes of multicomponent aerosols under controlled conditions. The Manchester Ice Cloud Chamber (MICC) is a fall-tube 10 m tall and 1 m in diameter, spanning 3 floors with a cold room on each, capable of reaching temperatures as low as -55°C. The chamber can also be pressure sealed and evacuated to as low as 50 mbar to simulate conditions found in the upper troposphere. Liquid water, mixed phase, or entirely glaciated clouds can be generated in the chamber, with cloud liquid water contents ranging from zero to the highest values found in nature.

Name: RvG-ASIC

Location: Norwich, UK

Coordinates: 52.622029, 1.239676

Specific focus: The RvG-ASIC facility at the University of East Anglia (UEA) comprises a coupled atmosphere–ocean–sea-ice–snow simulation chamber, which in this combination is unique in the world. RvG-ASIC was designed to investigate the role of first-year sea-ice on tropospheric chemistry, but can also be run in ocean-atmosphere mode (above –2 ºC), snow-atmosphere mode (no liquid water) or in dry mode for purely atmospheric investigations. It therefore provides a platform for a diverse range of multi-disciplinary experiments to study physical, chemical and biological between interactions between atmosphere, ocean, ice and snow.

Name: CASC

Location: Cambridge, UK

Coordinates: 52.198006, 0.125505

Specific focus: Indoor chamber. 5.4m3 collapsible FEP bag. 20 160W ultraviolet (UV) tanning lamps (> 300 nm) for use during photochemical-aging experiments and four 75W “hard” UV lamps (242 nm) for cleaning the chamber.

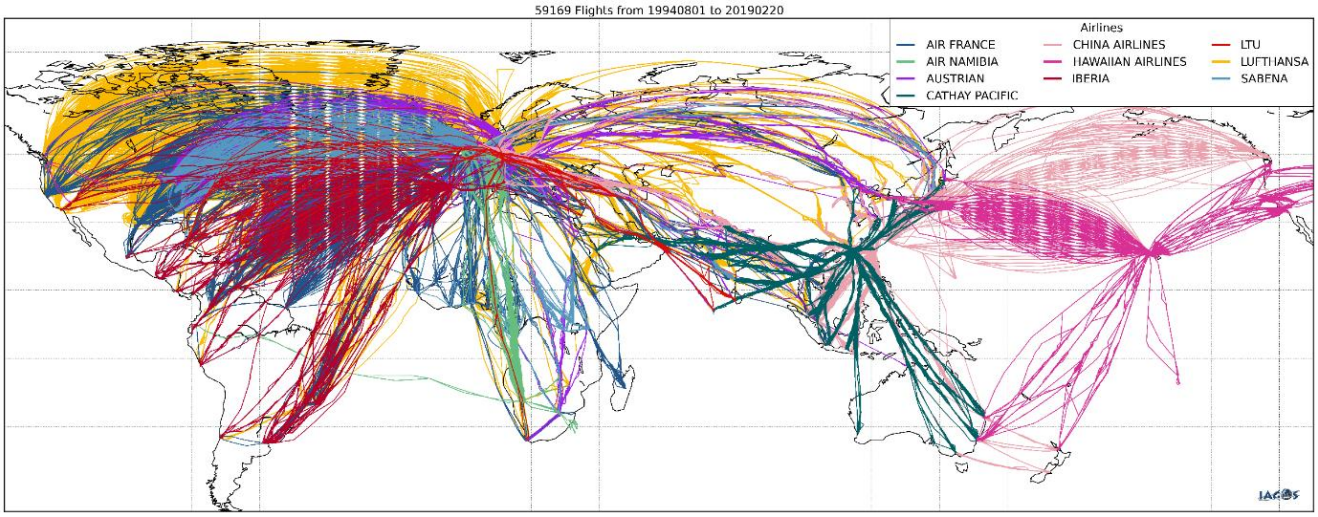
Instrumentation includes: Temperature, relative humidity, NO, NO2 (Mo converter instrument), O3, smps, PTR-ToF-MS, extractive electrospray ionisation (EESI) ultra-high resolution mass spectrometer, online reactive oxygen species instrument (OPROSI)

Unique features: Capability to monitor online and with high time resolution gaseous (PTRMS) and particle-phase molecular composition (EESI-MS) of VOC oxidation products at a molecular level. High time resolution quantification of reactive oxygen species instrument (OPROSI) to estimate particle toxicity.

E – List of HEMERA balloon launch bases

Launch bases	Country	Coordinates	Details
Esrange	Sweden	67° 53' N, 21° 04' E	payloads of up to 3000 kg; small, medium and large duration flights; circum-polar flights
Timmins	Canada	48° 28' 34.1436'' N, 81° 19' 51.0276'' W	
Aire sur l’Adour	France	43° 42' 22.471" N, 0° 15' 5.123" W	balloon technological and operational qualification tests, small balloons, e.g. SSBs

F - IAGOS flight routes



Appendix 2: Landscape of European ENVRIs in the marine domain and its further integration

Leading beneficiary: ICOS ERIC

Version: 3.0

Date	Authors, Beneficiaries	Version
20190916	Emmanuel Salmon, ICOS ERIC	Final
20190311	Daniela Franz, ICOS ERIC	Initial draft, for comments
20190426	Daniela Franz, ICOS ERIC Emmanuel Salmon, ICOS ERIC Janne-Markus Rintala, ICOS ERIC Jens Nejstgaard, AQUACOSM Michael Schultz, DANUBIUS-RI Annalisa Milano, ELIXIR Michael Mirtl, eLTER Nicolas Pade, EMBRC Juanjo Dañobeitia, EMSO ERIC Maria Incoronata Fredella, EMSO ERIC Hélène Leau, EMSO ERIC Sylvie Pouliquen, Euro-Argo Aodhan Fitzgerald, EUROFLEETS Glenn Nolan, EuroGOOS Benjamin Pfeil, ICOS ERIC Ingrid Puillat, JERICO-RI Laurent Delauney, JERICO-RI Alberto Basset, LifeWatch ERIC Christos Arvanitidis, LifeWatch ERIC Michèle Fichaut, SeaDataNet Heikki Lihavainen, SIOS	Commented and revised

Abstract

This study represents an analysis of the current landscape of European environmental research infrastructures (RIs) in the marine domain (including transitional and freshwater environments). The landscape is described from different perspectives, focusing on the relation of the RIs to Grand Challenges, their core competences and how they cover Essential Variables in marine research, as well as complementarities and collaborations. The analysis further comprises information on the scientific background of the RIs, the integration of the RIs into regional and global frameworks, complementarities and collaborations, user communities, services and products, station/ facility locations as well as data interoperability.

Ten RIs are considered in the analysis (AQUACOSM, DANUBIUS-RI, ELIXIR, eLTER, EMBRC, EMSO ERIC, Euro-Argo, EUROFLEETS, EuroGOOS, ICOS, JERICO-RI, LifeWatch ERIC, SeaDataNet, SIOS), differing in their maturity, sustainability and methods ranging from long-term observation networks and networks of experimental platforms to virtual and coordinating infrastructures. Some RIs are restricted to the marine domain, while others cover multiple domains in the environmental and Health and Food field.

The analysis aims to provide a clear view on the landscape and is of particular interest to foster a more efficient and comprehensive collaboration between the RIs and to support future strategic planning within the domain. The study will help to identify potential next steps in the collaboration towards an integrated observing system and to develop ideas for joint products and services following joint long-term research topics. The report will provide the domain-specific input for a white paper integrating all domains of the environmental field.

Abbreviations and acronyms

ENVRI	Environmental Research Infrastructure
ERIC	European Research Infrastructure Consortium
ESFRI	European Strategy Forum on Research Infrastructures
H2020	Horizon 2020
JRA	Joint Research Activity
NRT	Near Real-Time
RI	Research Infrastructure
RSS	River-sea system
RT	Real-Time
SMEs	Small and medium sized enterprises

Introduction

In this chapter the motivation and scope of the landscape analysis are described and the RIs involved are introduced.

Background and motivation

The European culture of cooperation and inclusiveness is exceptional compared to other regions of the world, where research is more competitive and less open science focused, and is strongly supported by common legal frameworks, which facilitate efficient governance and research funding. Research Infrastructures represent major elements of the competitiveness of the European Research Area (ERA). Intense collaboration between RIs is expected by the European funding agencies in order to optimise the landscape and strengthen the excellence and impact of European research.

The projects ENVRI (2011-2014, FP7-INFRASTRUCTURES-2011-1 – ID 283465) and ENVRIPLUS (2015-2019, H2020 INFRADEV-4-2014-2015 – ID 654182) have largely contributed to structure the complex landscape of Environmental and Earth System Research Infrastructures (ENVRI) in Europe and to join forces to tackle common challenges. ENVRIPLUS is bringing together research infrastructures (RIs), projects and networks as well as technical specialist partners to create a more coherent, interdisciplinary and interoperable cluster of Environmental Research Infrastructures across Europe, continuing and deepening the work done in the ENVRI project. The Board of European Environmental Research Infrastructures (BEERi) established under ENVRIPLUS is a major forum for the cooperative work between RIs.

ENVRIPLUS Deliverable 12.3 (Kutsch et al., 2017) made an important contribution towards a beneficial cooperation between European environmental research infrastructures (RIs) in the Terrestrial ecosystem domain. At its Zandvoort meeting (May 2018), the BEERi decided to produce a similar deliverable for the atmosphere and marine domains. The Executive Board of ENVRIPLUS assigned this duty to Task 17.1 (Facilitation of the communication and coordination at the domain level on the ENVRI strategy), Deliverable 17.6 (White paper on further integration of RIs in the environmental field including recommendations on co-locating research sites on national and international level).

The activities on this deliverable started in August 2018. Based on initial interviews with key persons of the RIs (see Appendix A – List of interview partners), the contents and expected outputs of the analysis were discussed during the ENVRI week in Riga (November 2018) and in a related BEERi strategy workshop. A concrete concept was developed and discussed in the BEERi meeting in Prague (January 2019).

The goal of Deliverable 17.6 is to foster a comprehensive and efficient cooperation between the RIs by providing a clear view on the current ENVRI landscape (and particularly, who is doing what and which niche each RI is occupying) and identifying potential joint long-term research topics as well as products and services. The deliverable will pave the way to address the Grand Challenges jointly, and thus more effectively, and will support the evolution of the RIs towards more service-oriented organisations, which produce synthetic knowledge services. The expected outputs are single domain reports for the atmosphere and marine domains and a final integrating white paper across domains of the environmental field, including Deliverable 12.3. The activities in Deliverable 17.6 are complementing the discussion on the future structural mode of the ENVRI community within Deliverable 17.5.

Scope of this report

This study aims to describe the current landscape of the European environmental RIs in the marine domain from different perspectives, and to analyse existing and develop new links between the RIs. **It is important to note that the report covers RIs addressing not only marine environments, but also transitional and**

freshwater environments (see section 0 for an explanation for the choice for the domain term; the RIs are here referred to as 'RIs in the marine domain').

The report will support the future strategic planning within the domain and can feed the discussion process among the involved RIs, user communities and stakeholders from national governments on the potentials for further collaboration between the RIs towards an integrated European observation system. Furthermore, the can help the RIs to respond jointly on upcoming calls in the next research funding programme of the EU. The report is planned to be utilized as an input to work package 9 of the ENVRI-FAIR H2020 project (2019-2022, H2020-INFRAEOSC-2018-2020 - ID 824068). For this purpose, the description of complementarities and the coverage of core variables as well as an initial inventory of the products and services provided by the RIs are of particular importance. Based on this information, ideas for joint products and services following joint long-term research topics can be developed. The report will provide the domain-specific input for the white paper integrating all domains of the environmental field, which will (as part of the updated ENVRI strategy) be proposed to the European Strategy Forum on Research Infrastructures (ESFRI;[47]) for consideration during the process of developing the ESFRI Roadmap 2021. The landscape is presented mainly with a narrative approach, as graphical representations fail to represent the landscape appropriately.

Explanation for the choice of the term for the domain

There is an ongoing discussion in the community on the terminology of the domain (marine vs. hydrosphere vs. aquatic). During a domain meeting in March 2019 (Final ENVRI week) it was decided to keep the marine domain term for the ENVRI community. We are aware that the term 'marine' is traditionally excluding freshwater environments. However, the term 'marine' is consistently used within the European and international landscape and acknowledges that 96.5 %[48] of the water on Earth is sea water.

The difficulty lies also in the fact, that marine and freshwater are a part of a continuity directly connected from rivers, lakes, wet-lands, groundwater, estuaries and open marine waters, which speaks for a need to be included in the same domain. Including freshwater environments into the Terrestrial ecosystem domain[49] would exclude the estuaries and other brackish water areas, that are particularly important in Europe, and where much of the human population lives.

The ESFRI Roadmap 2018 uses instead the term 'hydrosphere', which is compliant to the other domain terms used in the roadmap, and splits the domain into a marine part (from coast to deep oceans and ice caps) and a freshwater part (ice, groundwater, lakes, rivers, estuaries). The term 'hydrosphere' is more inclusive and acknowledges that freshwater may only be a few % of the water on earth but it is the critical factor for all life, especially human life with regard to drinking water supply, farming, industry, etc., that makes it importance for humanity much greater than the relatively modest volume. It is also one of the most threatened resources, and contains ca 10% of all biodiversity, despite its smaller volume. It is therefore a critical part of the grand challenges and needs to be clearly visualised.

However, the hydrosphere includes components such as clouds and precipitation, which are not covered reflected in the domain approach of the ENVRI cluster. The term might be an alternative in case the cluster move towards a cycle approach in the future. In addition, the term might cause confusion on the contents

[47] ESFRI is a strategic instrument to develop the scientific integration of Europe and to strengthen its international outreach.

[48] www.usgs.gov/special-topic/water-science-school/science/how-much-water-there-earth?qt-science_center_objects=0#qt-science_center_objects

[49] In fact, e.g., flux measurements over aquatic environments, as done in ICOS, are so far grouped into the Terrestrial ecosystem domain.

of the domain, whereas the term 'marine' is clearly defined and is recognised outside research, e.g. within the European Commission and the (offshore) industry.

Apart from the discussion on the terminology it is important to keep in mind that research has suffered from the traditional divide between freshwater and marine systems not only scientifically but also funding-wise. In consequence, parallel research domains developed, leading to less efficient use of resources. This hindered the understanding across systems, and has specifically under-stimulated science in estuary systems, where much of the world population lives, and thus experience some of the strongest pressures. One of the main aims of future RI-collaboration should be to remove this obstacle.

Research infrastructures included in the analysis

Reflecting the importance of the ocean and other water bodies covering about 71 %[50] of the Earth´s surface, the marine domain includes many actors. The landscape in this domain appears very complex, the complexity is amplified by numerous projects, regional and global frameworks, which are working on the cohesion of the community and a common strategic vision.

This landscape analysis involves all transnational European RIs of the marine domain (Euro-Argo, EUROFLEETS, EuroGOOS, JERICO-RI) and multi-domain RIs including the marine domain (ELIXIR, eLTER, EMBRC, EMSO ERIC, ICOS, LifeWatch ERIC, SIOS), which are directly participating in ENVRIPLUS, as well as ENVRIPLUS associated RIs (AQUACOSM, DANUBIUS-RI), and SeaDataNet as a virtual data management infrastructure (see **Virhe. Viitteen lähdettä ei löytynyt.**Table 1). The European Seas Observatory NETwork-Network of Excellence (ESONET-NoE), EMSO-PP and the Fixed-point Open Ocean Observatory network (FixO3), which are precursors of EMSO ERIC and participating in ENVRIPLUS, are not explicitly included. The analysis focusses on RIs identified by the ESFRI Strategy Working Group on Environment as long-term 'research facilities of pan-European importance that are necessary to strengthen scientific excellence and competitiveness in the EU' (ESFRI Roadmap 2018), but is not restricted to those. The analysis needs to reflect the broader landscape (beyond the ESFRI roadmap) in order to support further cooperation and integration, as there are several RIs that are not included in the ESFRI roadmap. The reasons are, for instance, that the RI is still in the community building process funded by the European Commission as Integrating Activity (for the community-building and integration of RIs) or it is at the beginning of the preparation phase as Design Study (for the development of new pan-European RIs), so it has not reached the maturity to be listed. Or, the RI is lacking the pan-European dimension that is required for ESFRI Landmarks or projects, is absent from the national roadmap processes and or missing political/ financial commitments to enter the ESFRI process (RI is trapped in an eternal perpetual project cycle).

[50] www.usgs.gov/special-topic/water-science-school/science/how-much-water-there-earth?qt-science_center_objects=0#qt-science_center_objects

TABLE 14: OVERVIEW ON RIS INVOLVED IN THIS ANALYSIS, REPRESENTING DIFFERENT MATURITY LEVELS. ESFRI PROJECTS ARE RIS IN THEIR PREPARATION PHASE, WHEREAS ESFRI LANDMARKS ARE RIS THAT WERE IMPLEMENTED OR REACHED AN ADVANCED IMPLEMENTATION PHASE UNDER THE ROADMAP AND THAT REPRESENT MAJOR ELEMENTS OF COMPETITIVENESS OF THE EUROPEAN RESEARCH AREA (ERA). DISTRIBUTED RIS CONSIST OF A CENTRAL HUB AND INTERLINKED NATIONAL NODES (ESFRI ROADMAP 2018). ERIC IS THE LEGAL FRAMEWORK FOR A 'EUROPEAN RESEARCH INFRASTRUCTURE CONSORTIUM' TO SUPPORT THE IMPLEMENTATION OF PAN-EUROPEAN RIS. AISBL IS AN INTERNATIONAL NON-PROFIT ASSOCIATION UNDER BELGIAN LAW.

RI	Status in ESFRI	Status of development/ legal status	RI type, section (according to ESFRI roadmap)	Focus	Website
ESFRI Landmarks					
ELIXIR (European infrastructure for biological information)	ESFRI Landmark in Health & Food domain (roadmap entry 2006)	ELIXIR Consortium Agreement (since 2013), operational since 2014	- Distributed - Multi-domain (Marine domain, Health & Food) - Virtual/ e-infrastructure: Marine biology, omics and bio-informatics	Managing and safeguarding of life science data	https://elixir-europe.org
EMBRC (European Marine Biological Resource Centre)	ESFRI Landmark in Health & Food domain (roadmap entry 2008)	ERIC (since 2018), operational since 2017	- Distributed - Multi-domain (Marine domain, Health & Food) - Observing/ experimental: Marine biology, omics and bio-informatics	Marine bioresources and marine ecosystems	www.embrc.eu
EMSO ERIC (European Multidisciplinary Seafloor and water column Observatory)	ESFRI Landmark (roadmap entry 2006)	ERIC (since 2016), pre-operational since 2016, planning to be fully operational in 2019	- Distributed - Multi-domain (Marine and Solid Earth domains) - Observing/ experimental: open ocean fixed point observatories	Environmental processes at the deep seafloor and in the ocean water column	http://emso.eu

RI	Status in ESFRI	Status of development/ legal status	RI type, section (according to ESFRI roadmap)	Focus	Website
Euro-Argo (European contribution to global Argo programme)	ESFRI Landmark (roadmap entry 2006)	ERIC (since 2014), operational since 2014	- Distributed - Observing: open ocean mobile platforms	Operational oceanography: linkage between the ocean and the Earth's climate	www.euro-argo.eu
ICOS (Integrated Carbon Observation System)	ESFRI Landmark (roadmap entry 2006)	ERIC (since 2015), planning to be fully operational in 2019; associated Implementation project: RINGO (Readiness of ICOS for Necessities of integrated Global Observations)	- Distributed - Multi-domain (Atmosphere, Terrestrial Ecosystem and Marine Domains) - Observing: Carbon cycle	Carbon cycle and greenhouse gases	www.icos-ri.eu
LifeWatch ERIC	ESFRI Landmark (roadmap entry 2006)	ERIC (since 2017), operational since 2017	- Distributed - Multi-domain (Terrestrial Ecosystem and Marine Domains) - Virtual/ e-infrastructure: Marine biology, omics and bio-informatics	Biodiversity and ecosystems	www.lifewatch.eu
ESFRI Projects					
DANUBIUS-RI (International Centre for Advanced Studies on River-Sea Systems)	ESFRI Project (roadmap entry 2016)	DANUBIUS-PP as H2020 Preparatory Phase Project (2016-2019), planning to be operational 2022	- Distributed - Observing/ experimental: River-sea systems	River-sea systems	www.danubius-ri.eu

RI	Status in ESFRI	Status of development/ legal status	RI type, section (according to ESFRI roadmap)	Focus	Website
eLTER (Long-Term Ecosystem Research in Europe)	ESFRI Project (roadmap entry 2018)	H2020 project (Integrating Activity, 2015-2019), planning to be operational in 2026	- Distributed - Observing: Long-term ecosystem research	Ecosystems in response to climate change	www.lter-europe.net/elter-esfri
Other projects					
AQUACOSM (EU network of mesocosms facilities for research on marine and freshwater ecosystems open for global collaboration)	(mentioned in ESFRI Roadmap Landscape analysis)	H2020 project (Integrating Activity, 2017-2020)	- Distributed - Experimental: large scale; freshwater/ marine mesocosms	(Access to) mesocosm facilities for ecosystem-scale experiments on marine and freshwater systems	www.aquacosm.eu
EUROFLEETS (European Research Fleets)	(mentioned in ESFRI Roadmap Landscape analysis)	EUROFLEETS Plus as H2020 project (Integrating Activity, 2019-2023)	- Distributed - Experimental: Research vessels	(Access to) research fleets	www.eurofleets.eu/np4/home.html
EuroGOOS (European Global Ocean Observing System)	(mentioned in ESFRI Roadmap Landscape analysis)	AISBL (since 2013), founded in 1994	- Distributed - Coordination/ communication network, data management: operational oceanography	Operational oceanography	http://eurogoos.eu
JERICO-RI	(mentioned in ESFRI Roadmap Landscape	JERICO-NEXT as H2020 Project (Integrating Activity, 2015-	- Distributed	Marine coastal	www.jerico-ri.eu

RI	Status in ESFRI	Status of development/ legal status	RI type, section (according to ESFRI roadmap)	Focus	Website
(Joint European Research Infrastructure network for Coastal Observatory)	analysis)	2019)	- Observing/ experimental: Coastal/shelf seas observatories	environments	
SeaDataNet	(mentioned in ESFRI Roadmap Landscape analysis)	SeaDataCloud as H2020 Project (Integrating Activity, 2016-2020)	- Semi-distributed - Virtual/ e-infrastructure: Data management	Ocean and marine data management, data discover and distribution	www.seadatanet.org
SIOS (Svalbard Integrated Arctic Earth Observing System)	(mentioned in ESFRI Roadmap Landscape analysis; was on roadmap 2008-2016)	Norwegian public (non-profit) limited company	- Distributed - Multi-domain (Atmosphere, Terrestrial Ecosystem and Marine Domains) - Observing: integrating long-term measurements	Integrating terrestrial, marine and atmospheric observations at Svalbard	https://sios-svalbard.org

All RIs are distributed RIs (semi-distributed in the case of SeaDataNet) and most of them address a broad scientific spectrum, with the exception of, e.g., the ocean-related component of ICOS, which focusses on oceanic carbon uptake and fluxes. The group of RIs considered in this analysis comprises:

- two pan-European long-term observation networks (eLTER, ICOS),
- one regional long-term observation platform (SIOS),
- two networks of experimental platforms (AQUACOSM, EUROFLEETS),
- two RIs networking (the institutions conduct observations, not the RI) or facilitating (RI conducts own measurements) both (long-term) observational and experimental studies (EMBRC, EMSO ERIC) together with two RIs in development (DANUBIUS-RI, JERICO-RI),
- two virtual infrastructures (e-infrastructures; LifeWatch ERIC and SeaDataNet),
- and two coordinating infrastructures, one for ocean observations (EuroGOOS) and one for life science resources (ELIXIR).

RIs facilitating long-term observations coordinate observations which are targeting specific scientific questions (science-driven). They provide their users with free and open access to, e.g., high-quality observational data, either long-term or campaign-based, as well as tools for quality assurance and various data products. SIOS, however, does not conduct its own observations, but integrates the observations of the partners to answer the scientific questions addressed. Experimental platforms are accessible for a wider community to address diverse research questions (user-driven). The experimental platforms are specialised to offer campaign-based physical access and facilitate exploratory process-oriented research, and manipulation studies in case of AQUACOSM. Among the central activities is the harmonisation of two traditionally separated research domains - marine and freshwater biological sciences - which has led to harmonised activities of even fundamental character such as use of compatible units and the adoption of cross-domain best practices for experimental process studies.

Major activities of the three virtual infrastructures are the coordination of resources in the form of management and archiving of big data, as well as the provision of Virtual Research Environments (VREs)[51]. In VREs users can access, analyse and further develop resources with web services and online tools. They can also produce synthetic knowledge from multi-disciplinary derived data through the VREs. While SeaDataNet focusses on its role as manager of oceanographic data and provider of respective standards and tools, ELIXIR and LifeWatch ERIC provide, in addition, resources for advanced data aggregation, analysis and modelling in virtual laboratories. Apart from Euro-Argo, all ESFRI Landmarks included in this analysis are covering several domains of the environmental field or address predominantly Health and Food aspects but have links to the environmental field (ELIXIR, EMBRC).

Marine research is more often (and exclusively in the case of EMSO ERIC, Euro-Argo, ICOS (ocean) and EuroGOOS) addressed by the RIs than freshwater and transitional environments: JERICO-RI (includes also brackish waters), AQUACOSM, DANUBIUS-RI, eLTER, LifeWatch ERIC and SIOS (include also river-delta/ estuary-sea systems, freshwaters), EMBRC (includes also river-delta/ estuary-sea systems), SeaDataNet (includes also river deltas/ estuary-sea systems and a few freshwater systems, which are close to coast). ELIXIR, EMBRC, LifeWatch ERIC and AQUACOSM particularly address biological topics. Operational oceanography is served by Euro-Argo, EuroGOOS, JERICO-RI and partly also ICOS, and might be served by EMSO ERIC in the future. SeaDataNet is not serving operational oceanography as it does not distribute Near Real-Time (NRT) data. Data from operational oceanography is exchanged, but not in Real-Time (RT).

[51] VREs/ virtual labs are web services for remote work on a specific topic and respective exchange between scientists, based on and tailored to the needs of the research community; e.g. when local working memory does not fit needs for computing. Virtual working environments are not a new idea, they have been in discussion for decades and evolved from different centres of excellence.

Biogeochemical variables are increasingly included in operational oceanography to observe and predict the effects of climate change on ocean metabolism, both physical and biological carbon uptake as well as lateral carbon transport. Changes in those can lead to ocean acidification and mass extinction of species which again will greatly alter the living marine resource management.

EUFAR (European fleet for airborne research) is a multi-domain RI, which is not specifically included in this analysis. It is described in more detail in the report for the atmospheric domain, to which it contributes most. EUFAR facilitates access to research aircraft as all-purpose experimental platforms allowing a broad spectrum of atmospheric observations and remote sensing of land/water surfaces (e.g., helping to understand land-surface interactions) and other user-driven applications. Airborne measurement campaigns as offered by EUFAR are also an efficient way of monitoring in lakes, rivers, pit land/wetlands, deltas, glaciers, coastal areas, especially in remote areas, using state of the art instrumentation like LIDAR, bathymetry LIDAR, RADAR, SAR RADAR, optoelectronic airborne sensors/instrumentation. Examples for specific applications are:

- Observations of inshore and freshwater systems are addressed by several EUFAR research platforms to quantify water quality and biological productivity;
- Observations that can lead to quantifying water cycle dynamics for hydrological prediction;
- Airborne active and passive observations for soil moisture;
- Pit land identification and assessment;
- Airborne bathymetric observations and water turbidity;
- Oil pollution observations in water.

A border research topic addressed by EUFAR (affecting all domains related to land, water and atmosphere) is related to human-built environment, in this context airborne remote sensing is being used for surface material identification (e.g., urban surfaces), as well as impact and evolution assessment.

Further not included in this analysis, but still linked to the marine domain, is the ESFRI Project **DiSSCo** (Distributed System of Scientific Collections), which entered the ESFRI Roadmap in 2018 along with eLTER RI. DiSSCo addresses the currently dispersed and fragmented access to European natural science collections, aiming to unify those resources and therefore strategically filling a gap in the European ENVRI landscape. The collections include marine and freshwater samples.

The landscape analysis might need to be updated regularly as the landscape is expected to change continuously especially due to the inclusion of new services, the building of new RIs, but probably also due to consolidation processes within the cluster. In addition, other research communities, facing the challenge of sustainability of project-based networks, might be integrated into existing RIs.

AQUACOSM is an Integrating Activity, unifying the marine and freshwater communities. Mesocosm experiments are by nature interdisciplinary and collaborative efforts. The H2020 project AQUACOSM builds on the marine FP7 project MESOAQUA. The pending proposal AQUACOSM-plus aims to facilitate closer collaboration with several RIs including DANUBIUS-RI, eLTER RI, ICOS, JERICO as well as global networking.

DANUBIUS-RI, the International Centre for Advanced Studies on River-Sea Systems, is very fast evolving considering that efforts to establish a RI started only in 2010 and the RI entered the ESFRI roadmap already in 2016. The RI is currently in the Preparatory Phase. It brings together fragmented, largely discipline-specific and often geographically isolated European research communities working on river-sea systems. Interactions started within a small group in the Danube region, funded by the Romanian government, which was growing progressively until a critical mass was reached and the scope extended to the whole of Europe.

ELIXIR is an intergovernmental organisation in life science and an ESFRI Landmark in the Health and Food field and consolidates national centres and core bioinformatics resources. While managing and safeguarding life science data, it deals with the increasing complexity of data, making it easier to find out the right tool and trainings, building a robust bioinformatics infrastructure, driving innovation and industry usage. Environmental research, including biodiversity, is a developing area of work in ELIXIR. The existing expertise in this area held by the nodes is currently mapped internally. ELIXIR is linked to the marine domain through its Marine Metagenomics Community[52], which developed a sustainable metagenomics infrastructure. ELIXIR is one of the four volunteering RIs for the Pilot Periodic Review of ESFRI Landmarks, that has been carried out to develop and test a methodology for the periodic update of the state of play of the ESFRI Landmarks.

eLTER is currently establishing the Integrated European Long-Term Ecosystem, Critical Zone and Socio-Ecological Research Infrastructure (eLTER RI) as an ESFRI RI. It is predominantly focusing on the terrestrial ecosystem domain (see ENVRIPLUS Deliverable 12.3), however, with some links to the marine domain. It comprises terrestrial, freshwater and transitional water sites, i.e. river-delta and estuary-sea systems, and provides fundamental long-term monitoring, e.g., of water quality. eLTER integrates a huge scientific community, its roots being laid in a series of flagship projects and processes in the field of ecosystem, critical zone and socio-ecological research such as ALTER-Net, the LTER-Europe[53] network of national networks, EnvEurope, ExpeER, the eLTER ESFRI process, the H2020 projects eLTER[54] and Advance_LTER[55]. eLTER has the current leadership in the International Long Term Ecological Research Network (ILTER[56]).

EMBRC is an ESFRI Landmark in the Health and Food field, however with strong (and increasing) links to the environmental field and, particularly, regarding the access to biota through the European Marine Stations. Environmental issues such as climate change, ocean acidification and biodiversity are of specific importance in several recent activities of EMBRC. With regard to the marine domain, EMBRC is dedicated to progress in marine biology and ecology research, assess the health of ocean ecosystems and develop enabling technologies through continuous monitoring.

EMSO ERIC is an integrated system of regional facilities at environmentally relevant key sites of the European seas (from North Atlantic to the Mediterranean Sea and the Black Seas). Both ESONET-NoE (2007-2011, FP6-funded network for open ocean observations: cable stations, moorings), EMSO-PP (2008-2011, project supported by FP7, aiming to establish the legal and governance framework for the infrastructure), and the Fixed point Open Ocean Observatory network (FixO3, two FP7 projects 2007-2013 and 2013-2017, offering an extensive TNA programme), were crucial for the development of this sustained activity. Many of the Esonet-NoE and FixO3 thematic modules and products were integrated into EMSO

[52] Metagenomics are about to revolutionise the biogeographic knowledge of species and habitats. ELIXIR has significant expertise and experience in marine metagenomics, notably via three of its Nodes: EMBL-EBI (European Molecular Biology Laboratory – European Bioinformatics Institute), ELIXIR Norway, and ELIXIR Hub. Current work is organised around the Marine Metagenomics Community (www.elixir-europe.org/communities/marine-metagenomics).

[53] LTER-Europe is the formal European regional group of the global ILTER network.

[54] The H2020 project eLTER aims at further developing the Long-Term Ecosystem Research infrastructure and science support in Europe.

[55] The H2020 project Advance_eLTER aimed to tackle elements of concern identified in the review of applications to the ESFRI Roadmap 2016 to support eLTER RI in entering the Roadmap.

[56] ILTER comprises about 800 ecosystem monitoring and research sites located in a wide array of ecosystems (terrestrial, aquatic, transitional waters), from single plot to large landscape scales to address various ecological questions and issues on human-environment interactions (socio-ecological systems) in their geo-physical framework. ILTER is a legal entity registered as an association in Costa Rica and consists of 44 member networks (regional or national). www.ilter.network/

ERIC. ESONET Vi worked as an extension of EMSO ERIC towards its user community, aiming to maintain the full consortium including those institutes which did not join the EMSO ERIC. The community network continued also with the H2020 projects EMSOLINK and EMSODEV. Products which were transferred to EMSO ERIC, such as the label for quality accreditation and certification of compliance with relevant EU and international standards, still need to be rebranded to EMSO.

Euro-Argo is the European pillar of the international Argo network, covering about 25 % of the array of > 3800 profiling floats measuring temperature and salinity every 10 days to a depth of 2000 m. Argo was designed in the late 1990s for observations of ocean circulation, to serve operational oceanography and climate studies. It is the first global in situ ocean observing network in oceanography. Argo progressively extends its portfolio towards deep ocean to understand how much and how fast the ocean warm up), to higher latitudes including partially ice-covered areas, as well as to coastal and marginal areas and biogeochemistry. For the latter new sensors are added to an increasing number of floats, measuring oxygen, nitrate, chlorophyll a, optics and pH. The aim is to understand changes in marine ecosystems including the ocean carbon pump, the coupling between physics and biology, and the effect of climate change on ocean chemistry and ecosystems. The two EU projects MOCCA and AtlantOS support the European contribution to ARGO.

The **EUROFLEETS** community has just started its third EU project following EUROFLEETS 1 (2009-2013) and EUROFLEETS 2 (2013-2017). The goal of the recent project EUROFLEETS Plus is the long-term sustainable organisation of a coherent and efficient fleet coordination by EUROFLEETS itself as a legal entity or under the framework of the European Research Vessel Operator (ERVO). In the project the future organisational structure will be determined, cruises will be expanded towards unique areas and observations will focus on the ocean and their changes (in particular, in the North Atlantic). EUROFLEETS is a key facility within European ocean research. The stakeholders are strongly involved to ensure that the RI provides access and services that are fit-for-purpose.

EuroGOOS is the European component of the GOOS Regional Alliances (GRAs) of the Global Ocean Observing System (GOOS) of the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO). It coordinates and supports five Regional Operational Oceanographic Systems (ROOS) in Europe. EuroGOOS can be seen as part of an intermediate layer for the coordination of activities of the marine domain. A significant number of the institutes contributing to marine RIs providing in situ observations are also members of EuroGOOS. EuroGOOS is working towards integrated, sustained and fit-for-purpose European ocean observations, underpinning the European Ocean Observing System (EOOS) framework.

ICOS provides long-term observations required to understand the present state and predict future behaviour of the global carbon cycle and greenhouse gas emissions and concentrations. As one of the few multi-domain RI ICOS integrates atmosphere, terrestrial ecosystem and ocean greenhouse gas observations. The oceanic component of ICOS is monitoring carbon uptake and fluxes in the North Atlantic, and the Nordic, Baltic, and Mediterranean Seas. Measurement methods include sampling from research vessels, moorings, buoys, and commercial vessels. The H2020 project RINGO fosters the scientific, geographical, technological, data-related as well as policy-related and administrative readiness of ICOS.

As an observing system of systems, **JERICO-RI** integrates several observing platform types and the associated technologies dedicated to the observation and monitoring of the European coastal waters. JERICO-NEXT is the current H2020 project supporting the European coastal research communities, and strengthening and enlarging the network of European operational services for coastal seas. It is the follow-on project of JERICO (2011-2015) towards the sustainability of JERICO-RI. The planned project JERICO-3 aims to increase the sustainability of the RI and introduce governance models. The community plans to

propose an ESFRI project in 2-3 years and to start the process of establishing an ERIC later on. Within JERICO-3 a stronger focus on biological observations and increased activities with regard to the land-sea continuum are envisaged.

LifeWatch ERIC is the pan-European e-infrastructure on biodiversity and ecosystem research, addressing biodiversity structure and organisation and ecosystems functioning and services issues from mountain-to-coastal and deep habitats. LifeWatch ERIC provides essential data on species, habitats (ecosystems) and, increasingly, gene information and metagenomics. It provides online options for model testing through its Virtual Research Environments (VREs). Although its main activity is on the development of the e-infrastructure, LifeWatch ERIC manages and properly cures the data from the observations carried out by its own communities, including plankton, benthos, bird and fish tracking, systems of sensors for abiotic recordings and acoustic sensors for marine species tracking. Some of the national nodes run oceanographic stations (e.g., LifeWatch-Belgium).

SeaDataNet is included in this analysis as an important part of the ENVRI cluster, although it exclusively acts as a virtual data management infrastructure without producing own data. Despite its maturity, SeaDataNet is not listed in the ESFRI Roadmap, as ESFRI does not recognise this kind of RIs. The SeaDataNet infrastructure was implemented during the projects SeaDataNet (2006-2011) and SeaDataNet2 (2011-2015), with a growing number of involved national data centres. The currently running H2020-project SeaDataCloud involves 42 data centres as partners of the project and providing data, whereas in total 113 data centres are connected to the RI SeaDataNet. SeaDataCloud aims at considerably advancing SeaDataNet services and increasing their usage, adopting cloud and HPC technology for better performance. The community plans to found an AISBL (statutes already written) before the end of SeaDataCloud in 2020. The process of establishing the AISBL is planned to be accompanied by the project SeadaCloud2 (submitted to the call H2020 INFRAIA-01-2018-2019). Whereas EMODnet unlocks specific data and makes them accessible (e.g., bathymetric data), and provides specific showcases, SeaDataNet represents an archive for all kinds of marine data. It functions as the database feeding EOOS, providing also the data management standards. EMODnet partly relies on data provided by SeaDataNet (e.g. in chemical and geophysical topics) in those cases in which EMODnet does not manage such data and develops data products.

SIOS constitutes an exception with regard to the geographical coverage as a regional observing system. It coordinates and integrates long-term measurements in and around the Norwegian archipelago of Svalbard and addresses a broad variety of Earth System Science questions. SIOS was on the ESFRI Roadmap from 2008 until 2016.

C. Landscape of environmental research infrastructures in the marine domain

In this chapter the landscape is analysed from different perspectives.

The landscape analysis exercise summarised in this document is closely linked to other recent activities in the European marine research community:

- The strategic planning and activities of the European Ocean Observing System (EOOS)[57]
- The European Strategy for the Atlantic Observing System under development in the H2020 AtlantOS project (Optimising and Enhancing the Integrated Atlantic Ocean Observing

[57] For the EOOS Consultations and derived Implementation Plan/ Strategy see www.eoos-ocean.eu/strategy-and-implementation/

Systems)[58]

- Landscape analysis conducted by JERICO-RI

C.1 Scientific background and relation to Grand Challenges

The need for ocean and coastal seas observations

Covering more than 70% of the earth's surface, the ocean plays a pivotal role in the earth's physical, geochemical and biological systems and as such affects us all. The ocean influences our weather and climate through its capacity to absorb, transport and emit radiation, heat and carbon. Through evaporation to cloud formation to rain, the ocean rejuvenates the Earth's drinking water. Ocean life recycles nutrients and is the basis of the planet's largest habitat. The ocean is a key factor for the Earth's ecosystem health and represents the largest and most complex system on Earth. Climate change affects ocean temperatures, acidity and stratification, and thus, marine species distribution and ecosystem functioning. The ocean is further the source of many natural risks (e.g., earthquakes, tsunamis, volcanism).

More than 40% of the global population lives in areas within 200 km of the ocean. Moreover, the doubling of the world population over the last 50 years, rapid industrial development, and the growing human demand for well-fare is exerting increasing pressure on the ocean and more particularly on the coastal and shelf seas that can experience huge damages.

Through fisheries and aquaculture, transport, energy, tourism, health and recreation, the ocean contributes directly to the economic wealth and security to a majority of nations. The degradation of coastal habitats, pollution, over-exploitation of fisheries, biodiversity decline, ocean acidification, causing the bleach and death of coral reefs, receding polar ice sheets, sea level rise, and ocean acidification are all raising awareness and concern among the public and policymakers, and threaten the well-being of the great numbers of the human population (over 40%) that live in coastal areas worldwide.

Despite the hereabove described issues related to the ocean, it still remains under-sampled and poorly known as a system. Moreover, there is a growing need for more systematic ocean information at local, national, regional, and global scales to support efforts to manage our relationship with the ocean. Thresholds in terms of magnitude and frequency should be set for the usage and exploitation of the ocean, but first the limits need to be known, for a sustainable ecosystem exploration.

As a consequence, the common mission of RIs settled in the marine domain is to provide interoperable observations of the different compartment (physics, geochemistry, biology), with capabilities to deliver FAIR qualified data to users and stakeholders.

For a long time, the ocean was not recognised appropriately. However, in recent years, the ocean community has made some big steps. In 2004, the United Nations General Assembly set up a regular process to review the environmental, economic and social aspects world's oceans and seas as the three pillars of sustainable development. In 2015, the UN adopted the Agenda 2030 for Sustainable Development and assigned the 14th global goal to the "Life Below Water". During the COP21 in France a first agreement with regard to the ocean was reached and its implementation discussed during the G7 Ise-Shima Summit in 2017. 2018 was then a critical year for European ocean research, with the development of a clear agenda how to move on together with a coordinated approach. The strategy and implementation Plan of a European ocean observing system (see above) was developed based on a consultation process coordinated

[58] www.atlantos-h2020.eu/download/deliverables/10.11%20Strategic%20foresight%20paper%20on%20AtlantOS%20in%20the%20European%20context.pdf

by EOOS, with strong response of national marine research institutes and universities. The EOOS conference in November 2018 addressed the fragmentation of the community (also beyond Europe and outside science) and identified gaps in order to make ocean observations fit-for-purpose.

The value chain of ocean observational data includes ocean observations provided, e.g., by RIs, ocean service (e.g., CMEMS as marine core service) as intermediate users and ocean economy as end-users. Observations are crucial for the value chain, however, they are not the goal, but the beginning and fundamental to assess, e.g., the effects of climate change. A gap in the process from data provision to information usage, e.g., by policy makers and the general public, was identified about five years ago and is addressed, for instance, by EOOS and Copernicus. LifeWatch ERIC and EMODnet have also taken some steps towards this direction by considering the production of the EBVs (Essential Biodiversity Variables), particularly through the GLOBIS-B project.

The need for observations of marine biodiversity

E.O. Wilson coined the term 'biodiversity' in the 1980s, when its decline was recognised as a global issue. Understanding the evolution and function of biodiversity and ecosystem services is highly needed, not only for scientific reasons, but also given the urgent challenges the world faces, for instance in coping with environmental change, disease epidemics and the provision of food, water and natural products, and many other ecosystem services for our living environment and welfare. In addition, mitigating biodiversity loss is one of the grand societal challenges. Biodiversity loss is increasingly influenced by anthropogenic-induced impacts, which can be summarised in population pressure and global change, resulting also in environmental constraints such as desertification, reduced water availability, and air quality, among others. Some of the major threats for marine biodiversity are fishing and removal of the ocean's invertebrate and plant stocks, many of which are overexploited; chemical pollution and eutrophication; physical alterations to coastal habitat; invasions of exotic species; and global climate change, including increased ultraviolet radiation and potentially rising temperatures, resulting in possible changes to ocean circulation (and thus nutrient supply and distribution). The International Maritime Organization (IMO) stated that the introduction of new species via ship ballast water is the third largest threat for marine environments, after pollution and the destruction of habitats.

One of the key elements of the UN Convention on Biological Diversity (CBD) is the set of Aichi Biodiversity Targets[59]. The UN Biodiversity Decade 2011-2020 highlighted the need of systematic observations of biodiversity on different scales. The way how biodiversity and ecosystem functioning research is done (how data is used by scientists, but also policy makers) has to change towards the usage of all available data and on the basis of interdisciplinarity. This requires a new level of facilities and transparency. Adding biological observations based on new technologies such as 'multi-omics' will dramatically improve the monitoring of the marine ecosystem status, its structure and function, and the services provided.

The need for observations in freshwater and transitional systems

Rivers, deltas, and coastal zones are experiencing ever-increasing pressures in recent years with drastic changes in land use, over-exploitation of natural resources, and hydraulic re-engineering. The resulting degradation has serious implications for human communities and environmental health. European research is world-leading but fragmented, largely discipline-specific and often geographically compartmentalised. There is similar compartmentalisation of policy and resource management, for example the disconnect between the EU's Water Framework and Marine Strategy Framework Directives. The lack of interdisciplinary RIs has fuelled this fragmentation. DANUBIUS-RI will fill the gap, drawing on

[59] www.cbd.int/sp/targets/

existing research excellence across Europe and enhancing the impact of European research. It is dedicated to overcoming disciplinary boundaries and will take a fundamentally new approach to support research addressing the conflicts between society's demands, environmental change and environmental protection in river-sea systems worldwide.

Relation to Grand Challenges

One option to describe the landscape of RIs in the marine domain is according to the scientific questions they address. Environmental research is key to understand and model the Earth system and its functioning in order to reduce environmental risks. Nowadays, the European Union orients its scientific funding programme particularly to Grand Challenges, i.e., research should be driven by the needs of society and the economy. Thereby, it supports RIs as 'facilities, resources and services used by the science community to conduct research and foster innovation' and as key elements of the European Research Area (ERA). Environmental RIs are linked to several frameworks addressing Grand Challenges for society and economy, including the UN Agenda 2030 which is anchored by Sustainable Development Goals (SDGs), covering a broad range of challenges, and some more specific frameworks such as the Paris Agreement (climate change, related to SDG13), the Rio Convention on Biological Diversity (CBD; loss of biodiversity; related to SDGs 14 and 15) and the Sendai Framework (disasters, related to SDG11). RIs contribute to the surveillance of those international agreements and assess their implementation.

The SDG system has 17 targets, whose progress is evaluated based on several specific indicators for each target. Environmental RIs mainly contribute to the progress on some of the targets, but do not specifically address the indicators. Most SDGs are closely linked to each other. RIs in the marine domain address particularly

- SDG 14 (Life Below Water),
- SDG 13 (Climate Action),
- SDG 9 (Industry, Innovation and Infrastructure, e.g. related to technological developments), and
- SDG 2 (Zero Hunger, with regard to marine food resources).

RIs such as ELIXIR provide access to life science data, which can be very heterogeneous in scope, and the various services derived from them. Thus, they are critical to bioinformatics research and its many applications in the fields of health (e.g. personalised medicine), food security (e.g. aquaculture) and the environment (e.g. pollution), which are of significant societal and economic benefits targeted in the SDGs.

Deliverable 12.1 of the ENVRIPLUS project provides an analysis on the relevance of some of the RIs (of the marine domain: EMBRC, EMSO ERIC, Euro-Argo, EuroGOOS, ICOS, LifeWatch ERIC) for the Grand Challenges defined in other classifications and provide comparable profiles of RIs in terms of their focal Grand Challenges. The following classifications were included:

- European Commission's (EC) Societal Challenges for Europe 2020 as priorities for the H2020 programme
- ICSU Earth System Science for Global Sustainability: The Grand Challenges
- US Natl. Research Council (NRC) Grand Challenges in Environmental Sciences

Initially, the ESFRI Grand Research Challenges, which were used for the 2014 ESFRI environmental RI interoperability and landscape analysis (Asmi et al. 2014[60]), were included as well, but turned out to be redundant. The ICSU classification reflects a 'workflow' view, while the EC and NRC challenges are 'topical',

[60] Global warming, climate change, volcanoes, energy, epidemic diseases, chemicalisation, earthquakes, air quality, fresh water, ocean acidification, deforestation, biodiversity loss, food supplies

with a more societal/political focus for the EC challenges and a stronger research/development aspect for the NRC classification. Of particular importance for the RIs of the marine domain are

- EC Grand Challenge 7 (Climate: Develop global environmental observation and information systems), and further
- EC Grand Challenge 5 (Climate: Environmental protection, sustainable management of natural resources, water, biodiversity and ecosystems, esp. EMBRC and LifeWatch ERIC) and
- EC Grand Challenge 6 (Climate: Fighting and adapting to climate change; esp. ICOS),

and with regard to the NRC classification:

- Grand Challenge 1 (Biogeochemical Cycles; esp. EMBRC, ICOS),
- Grand Challenge 2 (Biological Diversity and Ecosystem Functioning, esp. EMBRC and LifeWatch ERIC) and
- Grand Challenge 3 (Climate Variability; esp. EMSO, Euro-Argo and EuroGOOS).

TABLE 15: MISSIONS OF THE RIS, WHICH SDGS ARE ADDRESSED AND HOW.

RI	Mission	SDGs addressed	How the SDGs are addressed in detail
AQUACOSM	Strengthen EU network of mesocosm facilities and promote JRA, capacity building and standardisation in order to achieve a better understanding necessary to manage our future waters effectively	Climate Action (13)	Testing effects of changing climate in standardised conditions, i.e. effects of eutrophication, acidification, droughts, brownification, invasive species
		Clean Water and Sanitation (6)	Test environmental effects of toxication/ pollution (e.g. microplastics, blue-green algae blooms, light and chemical pollution are rapidly increasing)
		Life below water (14)	
DANUBIUS-RI	Enable and support research addressing the conflicts between society's demands, environmental change and environmental protection in river–sea systems worldwide and support their sustainable development	Zero hunger (2)	The support DANUBIUS-RI will provide to research and innovation in river-sea systems will contribute to the SDGs listed. At this stage, DANUBIUS-RI cannot specify in more detail how the SDGs are addressed, as DANUBIUS-RI is not operational yet but in the Preparatory Phase.
		Clean Water and Sanitation (6)	
		Sustainable cities (11)	
		Climate action (13)	
		Life below water (14)	
ELIXIR	Coordinate and develop life science resources across Europe so that researchers can more easily find, analyse and share data, exchange expertise, and implement best practices, in order to gain greater insights into how living organisms work.	Zero Hunger (2)	
		Good Health and Well-being (3)	
		Industry, Innovation and Infrastructure (9, esp. innovation)	
		Life below water (14)	
		Life on land (15)	

RI	Mission	SDGs addressed	How the SDGs are addressed in detail
eLTER	Understand the multiple effects of global change in European major ecosystems and socio-ecological systems by site-based, multi-scale and cross-disciplinary research into ecosystem structures and functions.	Climate Action (13)	
		Life on land (15)	
		Life below water (14)	
		Good Health and Well-being (3)	
		Clean Water and Sanitation (6)	
EMBRC	To enable research to further our understanding of marine ecosystems and biodiversity, understand the impact of climate change on them, and develop sustainable exploitation of marine environments and ecosystems. To develop marine solutions to society's grand challenges.	Life below water (14)	Research in all depths of the ocean to improve understanding of marine systems and services; ability to research effects of climate change in situ and in controlled conditions
		Climate Action (13)	e.g. effect of changes in temperature on organisms
		Industry, Innovation and Infrastructure (9)	Create new products from novel marine compounds; develop new instruments for marine research
		Zero Hunger (2)	Researching novel foods and protein sources from the sea; work towards sustainable aquaculture
		Responsible Consumption and Production (12)	Marine organisms as important links in recycling and waste management, e.g., studies on marine bacteria breaking down PET
		Good Health and Well-being (3)	Explore marine biodiversity for sources of new drugs, treatments, and pharmaceutics
		Decent Work and Economic Growth (8)	Support and underpin local biotechnology SMEs in coastal regions, generating new employment opportunities and local income streams

RI	Mission	SDGs addressed	How the SDGs are addressed in detail
EMSO ERIC	Setup smart regional facilities (seafloor and water column observatories) and tools to monitor EOVs	Life below water (14)	
		Climate Action (13)	
		(Industry, Innovation and Infrastructure (9))	
Euro-Argo	Continuous monitoring and NRT data provision of the temperature, salinity, and velocity of the upper ocean	Climate Action (13)	
		Life below water (14)	
EUROFLEETS	Coordinate (national) research vessel fleets in Europe, optimise the procedures, detect spare capacities and provide access to the facilities	Quality Education (4)	training for young scientists, Ocean literacy e.g. in schools
		Industry, Innovation and Infrastructure (9)	companies involved in equipping vessels
		Climate Action (13)	Vessel provision in support of Oceanic climate research across Atlantic /ice free Arctic
		Life below water (14)	Deep water ROV'S, Deep water capable vessels and Deep water AUV made available via TNA. JRA on tools for deep water research
EuroGOOS	Promote operational oceanography in European Commission and globally	14 (+ some others, however, the community is not fully aware of how they can contribute to SDG targets and indicators and is willing to engage when this is clarified)	Collecting the observations that may provide an input or an evidence base for policies or reporting commitments under SDGs.

RI	Mission	SDGs addressed	How the SDGs are addressed in detail
ICOS	Provide long-term observations required to understand the present state and to predict the future behaviour of the global carbon cycle and greenhouse gas emissions. ICOS (Ocean): measuring carbon uptake and fluxes in European Seas	Climate Action (13) Life below water (14), particularly 14.3	minimize and address the impacts of ocean acidification through enhanced scientific cooperation at all levels ➔ information on ocean acidification on annual basis requested; direct influence on SDG 14.3 in cooperation with NOAA
JERICO-RI	Providing a powerful and structured European Research Infrastructure dedicated to observe and monitor the complex marine coastal seas with capabilities to - provide services for the delivery of high quality environmental data, - access to solutions and facilities as services for researchers and users of the coastal marine domain, - create product prototypes for EU marine core services and users of the coastal domain, - support excellence in marine coastal research to better answer societal and policy needs. These, to make a valuable contribution to ongoing research, as well as to integrated assessments of the health and status of coastal/marine waters to meet national and international requirements. All data are free to access and use.	Zero Hunger (2)	Monitoring of phytoplankton aims at detecting harmful algal blooms that are endangering the marine food quality and it sanitary quality (fish farming and aquaculture)
		Life Below Water (14)	This is addressed by observing how affected the benthic habitat and phytoplankton populations are according their varying environment (physics and chemistry for instance)
		Climate Action (13)	Long term trend of key variables is acquired thanks to acquisition of data as long time series. + high frequency monitoring help observing extreme events related or not by global change
LifeWatch ERIC	The LifeWatch ERIC vision is to use and further develop the most advanced digital technologies and the existing data and knowledge to bring scientists, administrators	Zero Hunger (2)	A few virtual laboratories (vLabs) are targeting the agro-food domain
		Good-Health and Well-Being (3)	Ecosystem services are centrally placed in the e-infrastructure. These services include provision of

RI	Mission	SDGs addressed	How the SDGs are addressed in detail
	and managers, politicians and common people inside the Biosphere giving them the knowledge to understand the functioning of 'Our Live Supporting System' and allowing them to develop the actions to ensure its sustainability for the next decades. LifeWatch ERIC tackles global challenges, including biological diversity, ecosystem functioning and ecosystem services loss, invasive species and socio-economic impacts.		materials we use for health and food and others which guarantee a clean and healthy environment
		Quality Education (4)	The e-Infrastructure includes several citizen science web services and starts the development of high-education curricula in collaboration with Universities and Research Centres
		Clean Water and Sanitation (6)	Ecosystem services are centrally placed in the e-infrastructure. These services include provision of materials we use for health and food and others which guarantee a clean and healthy environment
		Industry, Innovation and Infrastructure (9)	LW ERIC not only provides cutting-edge VREs, which function as innovation chambers, but also endless options for common venture investments with the industry and private sector; (11) Several vLabs deal with urban ecology (e.g. bird tracking and urban channel water quality)
		Sustainable cities and communities (11)	Several vLabs deal with urban ecology (e.g. bird tracking and urban channel water quality)
		Climate Action (13)	The modelling the non-invasive species geographic expansion, as facilitated by multiple vectors, is designed for the Internal Joint Initiative (IJI) VRE, in the Strategic Working Plan of LW ERIC
		Life below water (14)	The marine VRE is the most powerful in LifeWatch ERIC, with many vLabs and e-Services dedicated on biodiversity and ecosystem data and data observatories provision, exploration and analysis for all type of users. The terrestrial VRE follows closely but with fewer applications, for the time being
		Life on land (15)	The marine VRE is the most powerful in LifeWatch ERIC, with many vLabs and e-Services dedicated on biodiversity and ecosystem data and data observatories provision,

RI	Mission	SDGs addressed	How the SDGs are addressed in detail
			exploration and analysis for all type of users. The terrestrial VRE follows closely but with fewer applications, for the time being
SeaDataNet	Management of oceanographic data (physical, chemical, geological, biological) and its steadily improvement	Life below water (14)	
		Zero Hunger (2)	
		Good Health and Well-being (3)	
		Quality Education (4)	
		Clean Water and Sanitation (6)	
		Affordable and Clean Energy (7)	e.g. offshore wind parks
		Industry, Innovation and Infrastructure (9)	
		Climate Action (13)	
		Partnerships for the Goals (17)	goal to develop partnerships
SIOS	Build an observing system to provide added value to Earth System Science in the high Arctic. (Scientific questions, which are extremely broad, are currently refined, as also the core variables, and annually updated)		

C.2 Competence portfolios and coverage of core variables in marine research

C.2.1 Competence portfolios

The core competences of the RIs need to be pointed out clearly in order to make use of complementarities and foster collaboration between the RIs.

RI	Core competences
AQUACOSM	- Network of aquatic mesocosms (ecosystem-scale experiments) that brings together the marine and freshwater research domains (from mountains to ocean: river, lakes, estuaries, coastal and open ocean, Arctic to the Mediterranean), integrating freshwater and marine communities also in direct standardised mesocosm-studies (Joint Research Activities, JRA, on coordinated pilot studies across salinity gradients, and geographical north south gradients) - Access to and harmonisation between mesocosm facilities for ecosystem-scale experiments on marine and freshwater systems to obtain a quantitative understanding of ecosystem-level impacts of stressors in complex systems - Experimental manipulation studies/ scenario tests provide observational data for parameterisation and evaluation of models (focus on climate change scenarios[61]) - Includes facilities with unique and lading capabilities, such as the only open ocean capable mesocosm facility, the world's longest running facility, the world's longest running single experiment, and includes the presently largest and highly instrumented aquatic mesocosm facilities, conducted the first experiments worldwide on several topics, including ocean acidification and light pollution
DANUBIUS-RI	- Facilitates studies of river-sea systems (RSS), addressing particularly the conflicts between society's demands, environmental change and environmental protection - Allows for analysis of the entire RSS (continuum) with focus on transitional zones, which are of special importance for society, and the development of management solutions - Brings together the fragmented, discipline-specific (natural science, socio-economics, engineering, etc.) and often geographically isolated European research on RSS (strongly interdisciplinary approach) - Harmonises and provides access to a range of European river-sea systems, existing facilities and expertise
ELIXIR	- Coordinates and develops life science and bioinformatic resources across Europe, including databases, software tools, training materials, cloud storage and supercomputers - Uniting Europe's leading life science organisations in managing and safeguarding the increasing volume of data and knowledge

[61] Mesocosm based experimentation is presently the main tool to directly test predictions of climate change and other stressors on complex natural systems, based on e.g. forecasts from Long-Term Ecosystem Monitoring and modelling.

RI	Core competences
	- Supports development of sustainable metagenomics infrastructure with the potential to provide a broad range of industrial applications
eLTER	- Hypothesis-driven long-term ecosystem research at a nested system of sites at multiple spatial scales: site-specific observations considering the specific needs - 'Whole system approach' to observe and analyse the environmental system, encompassing biological, geological, hydrological and socioecological perspectives[62] - Includes an 'Long Term Socio-economic and Ecosystem Research' (LTSER) component focusing on the direct societal relevance and the embedded tools for analysing features linked to societally-relevant properties (e.g. competing land uses, protection of recreational values, preservation of drinking water, etc.)
EMBRC	- Portal to a comprehensive range of services, resources and knowledge in marine biology and ecology research (long-term ecological monitoring), key thematic areas include marine biodiversity, ecology, and ecosystem function, developmental biology and evolution, marine products and resources (biotechnology, aquaculture, fisheries), biomedical science, but also, ocean acidification, biological oceanography - Unlocks the potential of the marine realm for new biomaterials, develop scenarios for changing ocean, develop enabling technologies, standards and methods and supporting scientific breakthroughs and applications in medicine, nutrition and aquaculture - Central role in development and validation of comprehensive approaches to study the water column and environmental monitoring, and deployment of a network of augmented ocean observatories, including genomics, imaging, and ARMs, to compliment the long-term data series that exists in many EMBRC sites - Access clearance and facilitated procedures for researchers to marine genetic resources in compliance with the Nagoya Protocol and Access and Benefit sharing regulations
EMSO ERIC	- Open ocean fixed point multidisciplinary observatories, from the sea surface (up to 1 m below sea surface) to sea-floor and sub-seafloor: observation of physical and environmental variables to understand complex interactions between the geosphere, biosphere and hydrosphere - Development of new sensor technologies - Document and study episodic events which are difficult to detect by short-term marine expeditions, such as earthquakes, tsunamis, slope stabilities, hydrothermal vents, benthic storms, biodiversity changes, pollution, gas hydrate (methane) release, dense water cascades, plankton booms, water mass movements, influence of eddies

[62] The intersection of two conceptual models defines the 'Whole System Approach' for life support systems in the Anthropocene: the Press Pulse Dynamic (PPD) Model as horizontal component without specific reference to spatial scale, (i.e. it can be applied at any scale scale) and the spatially-nested hierarchical feedback paradigm of Macrosystems Ecology (MSE) as a vertical component, including within scale and cross scale interactions.

RI	Core competences
Euro-Argo	- Argo is the first global in situ ocean observing network in oceanography: provides a global array of profiling floats measuring water temperature and salinity every 10 days to a depth of 2000 m, as important complement to satellite observations - increasingly dense array of biogeochemical measurements
EUROFLEETS	- Coordination of access to European marine research vessels and equipment, optimising campaign schedules in view of the expensive ship time: user-driven application, from sea surface to seafloor - Development of long-term vision for provision of pan-European TNA access - Development of tools and software for deep water exploration and research - Utilisation of latest technologies for telepresence approach to deep water research
EuroGOOS	- Promotes operational oceanography with a full value chain approach: observations and integration towards fit-for-purpose products and services - Coordination of five Regional Operational Oceanographic Systems (ROOS) - EuroGOOS working groups, networks of observing platforms (task teams), and ROOS provide fora for cooperation, unlocking quality marine data and delivering common strategies, priorities and standards - Delivering strategies, priorities and standards towards an integrated European Ocean Observing System (EOOS) involving ocean health, real time services and climate observations
ICOS (ocean)	- monitoring carbon uptake and fluxes in European Seas (esp. North Atlantic, Nordic Seas, Baltic, and the Mediterranean Sea): NRT data of surface ocean pCO_2 and atmospheric CO_2 concentrations over the ocean (+ associated variables) at fixed ocean stations or onboard voluntary observing ships, marine flux towers - expertise in quality assurance and control (based on standard operating procedures) - integration with observations in terrestrial/ limnic ecosystems and atmosphere for a multi-scale analysis of greenhouse gas emissions and carbon cycle, human and natural drivers, processes and controlling mechanisms, regional budgets
JERICO-RI	- Integrating observations and competences in physics, biology and biogeochemistry of the marine coastal environment allowing an ecosystem approach from the bottom to the sea surface-European network of coastal observatories: Integration of (existing) infrastructures and of access to data and tools - Expertise and development of best practices (instrument application, quality assessment, etc.) in six observing systems: gliders, fixed platforms, ferryboxes, HF radars, bottom-based observatories, coastal profilers, and related data flows - Promoting the measurement of a shared list of priority variables at all observatories addressing the needs of environmental monitoring, Regional Sea Conventions, the Water Framework

RI	Core competences
	Directive[63] and the MSFD
LifeWatch ERIC	- Distributed virtual laboratory: Managing and providing access to a multitude of datasets as well as of data aggregation, analysis and modelling services, and services and tools enabling the construction and operation of virtual research environments (VREs) where specific issues related with biodiversity, and ecosystem research are addressed, including research focusing on biodiversity and ecosystem conservation, ecosystem re-naturalisation and re-construction - Facilitates and promotes changes in scientific practice towards big data synthesis **Marine domain:** - Access to aggregated data resources on marine biodiversity (genomic, trait, taxonomic and functional diversity) and marine ecosystem functioning, by integrating resources originally developed by different large and global scale initiatives (e.g., WoRMS, GBIF, GEO) and resources developed within LifeWatch ERIC (e.g., gene, traits and morpho-functional trait data, species and habitat data and sets of ecosystem level information) - Marine-VRE for understanding on marine metagenomics, ocean carbon sequestration and acidification, ecological and environmental status assessment of marine environments
SeaDataNet	- Providing timely and high-quality access to broad spectrum of marine metadata, data and data products (with focus on in situ data) - Defining, adopting and promoting common data management standards and realizing technical and semantic interoperability with other relevant data management systems and initiatives on behalf of science, environmental management, policy making, and economy
SIOS	- Multi-domain RI for coherent and comprehensive research in Svalbard region, answering key questions in Earth System Science (especially Arctic amplification, Arctic water cycle, anthropogenic forcing), focus on Svalbard land mass and biota interactions with changing climate - Infrastructure optimisation - SIOS is coordinating the long-term monitoring, the participating stations themselves have additional campaigns

C.2.2 Core variables in marine research and their coverage by the RIs

Assembling sets of relevant variables facilitates prioritisation of requirements, optimised observations and monitoring, as well as focused and coordinated action (Bojinski et al., 2014). This is of great advantage for ocean observations, considering their high costs and the difficult conditions under which they are gathered. 'Essential Variables' represent the first level of abstraction between low-level primary observations and high-level indicators of, e.g., climate and biodiversity, and thus, are of particular importance for the interaction between researchers and decision-makers. There are many systems of 'Essential Variables' on the market, e.g., developed within projects (as subset of the essential variables in the H2020 project SEACRIFOG, see López-Ballesteros et al., 2018), or the Essential Carbon Cycle Variables defined within the

[63] http://ec.europa.eu/environment/water/water-framework/index_en.html

COCOS project). However, here we only focus on the ones developed by programmes with a clear mandate by global organisations.

Ocean and freshwaters play an important role in the global climate system and (ocean in particular) host the majority of biodiversity. Three essential variable systems are of relevance for the marine domain: the Essential Climate Variables, the Essential Ocean Variables and the Essential Biodiversity Variables (see sections C.2.2.1, C.2.2.2 and C.2.2.3).

C.2.2.1 Essential Climate Variables (ECVs)

An ECV[64] is a physical, chemical or biological variable or group of linked variables that critically contributes to the characterisation of Earth's climate (Bojinski et al., 2014). They represent the most mature set of 'Essential Variables', e.g., in comparison to Essential Ocean Variables (EOVs) and Essential Biodiversity Variables (EBVs). The selection of ECVs is regularly maintained by the Global Climate Observing System (GCOS) expert panels and based on three criteria: relevance, feasibility and cost effectiveness. ECVs are observed according to the GCOS Climate Monitoring Principles[65]. GCOS is a programme which regularly assesses the status of global climate observations and produces guidance for its improvement, mandated by WMO, the Intergovernmental Oceanographic Commission of UNESCO, the United Nations Environment Programme, and the International Science Council. It works towards accurate, sustained, freely and openly available global climate observations.

Systematically observing ECVs aims to solve challenges in climate research and support climate services and mitigation and adaptation measures. ECVs are broadly adopted in science and policy. Many activities globally and in Europe, e.g. in WMO, the United Nations Framework Convention (UNFCCC) and Copernicus, are structured along the ECVs. They have been identified as a key element of the observations and monitoring pillar of the WMO programme GFCS (Global Framework for Climate Services). In compliance with their purpose to tackle grand environmental challenges, RIs should contribute to sustained observations of ECVs. The RIs in the marine domain address particularly the ECVs in the two variable groups Atmosphere (Surface) and Ocean (Physical, Biogeochemical and Biology/ Ecosystems).

[64] https://public.wmo.int/en/programmes/global-climate-observing-system/essential-climate-variables
[65] http://ane4bf-datap1.s3-eu-west-1.amazonaws.com/wmocms/s3fs-public/ckeditor/files/GCOS_Climate_Monitoring_Principles.pdf?l1e4ALNYxVIStmm19we2Sz0evxEFpHmT

TABLE 16: CURRENT LIST OF ECVS AND RESPECTIVE DATA PRODUCTS[66], WHICH ONES ARE PROVIDED BY RIS, WERE QUANTITIES ARE PROVIDED BY RIS WHICH ARE CLOSELY RELATED TO THE ECV AND FROM WHICH THE PRODUCT CAN BE DERIVED, AND OTHER CONTRIBUTIONS (PROVISION OF SUPPLEMENTAL OBSERVATIONS, TECHNOLOGICAL IMPROVEMENT, E.G., INCREASING THE ACCURACY OF MEASUREMENTS AND PIONEERING CAPABILITIES TO MEASURE NEW VARIABLES).

ECV	Product (ECV dataset)	Addressed by RI		
		Provision of product	Provision of quantities from which the product can be derived	Other contributions
Atmosphere – Surface				
Precipitation	Estimates of liquid and solid precipitation			
Pressure (surface)	Pressure	EUROFLEETS vessels enabled with met stations directly providing		
Surface Radiation Budget	Surface ERB longwave			
	Surface ERB shortwave			
Surface Wind Speed and direction	Surface wind speed and direction	EUROFLEETS vessels enabled with met stations directly providing		
Temperature (near surface)	Temperature	EUROFLEETS vessels enabled with met stations directly providing		
Water Vapour (surface)	Water vapour			
Land - Hydrosphere				
River discharge	River discharge			

[66] Current ECV requirements according to the GCOS 2016 Implementation Plan, Annex 1:
Atmosphere: http://ane4bf-datap1.s3-eu-west-1.amazonaws.com/wmocms/s3fs-public/ckeditor/files/ECV-Atmosphere_requirements_IP2016.xls?vz8ZpZfeaewO8vVjYgSx8k204SPP3Keo
Ocean: http://ane4bf-datap1.s3-eu-west-1.amazonaws.com/wmocms/s3fs-public/ckeditor/files/ECV-Ocean_requirements_IP2016.xls?fzLV7g7QVzmWFqaZkYUBXUa_8DPq2UZZ

ECV	Product (ECV dataset)	Addressed by RI		
		Provision of product	Provision of quantities from which the product can be derived	Other contributions
	Water level			
	Flow velocity			
	Cross-section			
Lakes	Lake water level			
	Water extent			
	Lake surface water temperature			
	Lake ice thickness			
	Lake ice cover			
	Lake colour (lake water leaving reflectance)			
Ocean – Physical				
Ocean Surface Heat Flux	Latent heat flux			
	Sensible heat flux			
Sea ice	Sea ice concentration			
	Sea ice extent/ edge			
	Sea ice thickness			
	Sea ice drift			
Sea level	Global mean sea level			
	Regional sea level			- DANUBIUS-RI: studies impact of sea-level rise on RSS
Sea state	Wave height		- EMSO ERIC	
Sea surface salinity	Sea surface salinity	- Euro-Argo: in 2-2000	- EMSO ERIC: surface to seafloor	

ECV	Product (ECV dataset)	Addressed by RI		
		Provision of product	Provision of quantities from which the product can be derived	Other contributions
		m depth[67] - EUROFLEETS vessels enabled with Oceanographic sensors directly providing		
Sea surface temperature	Sea surface temperature	- Euro-Argo: sea surface to 2000 m	- EMSO ERIC: surface to seafloor	
Subsurface currents	Interior currents	EUROFLEETS vessels directly providing via ADCP		
Subsurface salinity	Interior salinity	EUROFLEETS vessels directly providing via CTD		
Subsurface temperature	Interior temperature	EUROFLEETS vessels directly providing via CTD		
Surface currents	Surface Geostrophic Current	- JERICO-RI: high frequency radar maps		
Surface stress	Surface stress			
Ocean – Biogeochemical				
Inorganic carbon	Surface Ocean Partial Pressure of CO_2 (p CO_2)	ICOS		
	Subsurface ocean storage of CO2		- EMSO ERIC: seafloor	
Nitrous oxide	Interior ocean N2O			
	N2O air-sea flux			
Nutrients	Interior ocean concentrations of	- Euro-Argo: sea surface to 2000 m	- EMSO ERIC: surface to 100 m	

[67] Measurement are limited instrument-related to max. 2 m below sea surface

ECV	Product (ECV dataset)	Addressed by RI		
		Provision of product	Provision of quantities from which the product can be derived	Other contributions
	silicate, phosphate, nitrate	- JERICO-RI: ferrybox and buoys time series	depth	
Ocean colour	Water Leaving radiance			
	Chlorophyll-a concentration	- Euro-Argo: sea surface to 2000 m	- EMSO ERIC: seafloor	
Oxygen	Interior ocean oxygen concentration	- Euro-Argo: sea surface to 2000 m - JERICO-RI	- EMSO ERIC: 100 m depth to seafloor	
Transient tracers	Interior ocean CFC-12, CFC-11, SF6, tritium, 3He, 14C, 39Ar			
Ocean – Biological/ Ecosystems				
Marine Habitat Properties	Coral Reefs			
	Mangrove forest			
	Seagrass beds			
	Macroalgal communities			EMBRC: LTER data
Plankton	Phytoplankton	- JERICO-RI: ferrybox phytoplankton transect in time series		EMBRC: LTER data
	Zooplankton			EMBRC: LTER data

C.2.2.2 Essential Ocean Variables (EOVs)

Essential Ocean Variables (EOVs) are identified and respective specifications defined by three Expert Panels of the Global Ocean Observing System (GOOS) representing their specific discipline: Physics and Climate Expert Panel (provided by the Ocean Observations Panel for Climate, OOPC), Biogeochemistry Expert Panel (provided by the International Ocean Carbon Coordination Project, IOCCP), and Biology and Ecosystems

Expert Panel. GOOS coordinates global ocean observations in the three disciplines across three cross-cutting themes: Climate (through GCOS; particularly Physics and Biogeochemistry, but also Biology and Ecosystems), Operational Ocean Services (e.g., through JCOMM services; particularly Physics, but also Biogeochemistry), and Ocean Health (e.g., with GEO; particularly Biogeochemistry and Biology and Ecosystems, but also Physics)[68].

The EOV specifications include, e.g., addressed phenomena (e.g., ocean circulation, food webs), sub-variables, spatial and temporal sampling schemes, supplemental observations, observing options and data management practices. EOVs are selected based on their relevance to the overall GOOS themes, the technical feasibility of their observation on a global scale (using proven, scientifically understood methods) and the cost effectiveness of generating and archiving the data. Some of the variables are inherited from the list of ECVs. The compilation of the EOVs is still ongoing. In particular, the variables for Biology and Ecosystems are not sufficiently specified.

For example, ICOS is the most important supplier of pCO_2 data to GOOS, supplemented by project-based observations. JERICO-RI encourages coastal observatories to measure a shared list of variables (water temperature, salinity, acidity (pH), turbidity, chlorophyll a, dissolved oxygen (O_2), pCO_2 and biological variables) including some EOVs. LifeWatch ERIC has a strong impact on EOVs in the Biology and Ecosystems section, and EBVs. EMSO ERIC covers seven EOVs and has additional resources available for fluorescence/ chlorophyll a, pH, partial pressure of carbon dioxide (pCO_2), partial pressure of methane (pCH_4), and imaging cameras. EMSO ERIC observes acoustic ambient noise in the ocean to

TABLE 17: CURRENT LIST OF EOVS[69], WHICH ONES ARE PROVIDED BY RIS, WHERE QUANTITIES ARE PROVIDED BY RIS WHICH ARE CLOSELY RELATED TO THE ECV AND FROM WHICH THE PRODUCT CAN BE DERIVED, AND OTHER CONTRIBUTIONS (PROVISION OF SUPPLEMENTAL OBSERVATIONS, TECHNOLOGICAL IMPROVEMENT, E.G., INCREASING THE ACCURACY OF MEASUREMENTS AND PIONEERING CAPABILITIES TO MEASURE NEW VARIABLES).

EOV	Addressed by RI		
	Sub-variable	Provision of product or quantities from which a product can be derived	Other contributions
Physics			
Sea state		Collected by EuroGOOS ROOS in all physics variables	
Ocean surface stress			
Sea ice			

[68] The GOOS strategic mapping tool provides an overview of those themes with respect to their links to the EOVs and how they contribute to societal benefits in accordance with GOOS mandates: www.goosocean.org/index.php?option=com_content&view=article&id=120&Itemid=277.

[69] EOV Specification Sheets including sub-variables and derived products are available at: www.goosocean.org/index.php?option=com_content&view=article&id=14&Itemid=114

EOV	Addressed by RI		
	Sub-variable	Provision of product or quantities from which a product can be derived	Other contributions
Sea surface height			
Sea surface temperature	- EUROFLEETS vessels directly providing - JERICO-RI: ferrybox transect in time series, surface buoys		
Subsurface temperature	- JERICO-RI: time series from buoys		
Surface currents	- JERICO-RI: high frequency radar maps		
Subsurface currents	EUROFLEETS vessels directly providing		
Sea surface salinity	EUROFLEETS vessels directly providing		
Subsurface salinity	- EUROFLEETS vessels directly providing - JERICO-RI: time series from buoys		
Ocean surface heat flux			
Biogeochemistry			
Oxygen	- JERICO-RI: time series from buoys and ferry boxes		
Nutrients	- JERICO-RI: time series from buoys and ferry boxes		
Inorganic carbon			
Transient tracers			
Particulate matter	- Euro-Argo: sea	- EMSO ERIC: 100 m	

EOV	Addressed by RI		
	Sub-variable	**Provision of product or quantities from which a product can be derived**	**Other contributions**
	surface to 2000 m	depth to seafloor	
Nitrous oxide			
Stable carbon isotopes			
Dissolved organic carbon			
Biology and Ecosystems			
Status of functional groups			
Phytoplankton biomass and diversity			EMBRC: LTER data
Zooplankton biomass and diversity			EMBRC: LTER data
Fish abundance and distribution			EMBRC: LTER data
Marine turtles, birds, mammals abundance and distribution			
Microbe biomass and diversity *(In definition phase)*			EMBRC: LTER data
Invertebrate abundance and distribution *(In definition phase)*			EMBRC: LTER data
Health of living ecosystems			
Hard coral cover and composition			
Seagrass cover and composition			
Macroalgal canopy cover and composition			EMBRC: LTER data
Mangrove cover and composition			
Cross-disciplinary			
Ocean colour			
Ocean sound	EMSO ERIC: acoustic		

EOV	Addressed by RI		
	Sub-variable	Provision of product or quantities from which a product can be derived	Other contributions
	ambient noise[70]		

C.2.2.3 Essential Biodiversity Variables (EBVs)

The framework of Essential Biodiversity Variables (EBV) is developed by the Group on Earth Observations Biodiversity Observation Network (GEO BON). EBVs are defined as the derived measurements required to study, report, and manage biodiversity change, focusing on status and trend in elements of biodiversity. The variables defined as EBVs have been gathered for decades by ecologists. Assembling them helps to prioritise biodiversity variables that inform about the most important functional and structural components of ecosystems (Pereira et al. 2013, Proença et al., 2017). An ideal EBV is

- able to capture critical scales and dimensions of biodiversity,
- biological,
- sensitive to change,
- describing a state and ecosystem agnostic, as well as
- technically feasible, and
- economically viable and sustainable in time.

Furthermore, EBVs should be

- able to be measured or modelled globally[71],
- capitalize from integrating remote sensing with in situ observations,
- be relevant to the broader community, which is working towards the 2020 Targets of the Convention on Biological Diversity (CBD[72]), and
- provide the foundation for developing biodiversity forecasts under different policy and management scenarios.

The compilation of the EBVs is still ongoing. The assembled EBV candidates are aggregated in six classes: Genetic composition, Species population, Species traits, Community composition, Ecosystem structure, and Ecosystem function.

The system-focused and integrated observation schemes of eLTER will be based on the Ecosystem Integrity (EI) and the EBV frameworks (Haase et al. 2018). Both frameworks are complementary, with the EI framework covering more comprehensively the abiotic variables at monitoring sites and the EBV framework covering more comprehensively the biotic variables. Discussions are ongoing to adopt a combination of both frameworks for future site-based long-term ecosystem research.

C.3 Integration of research infrastructures into regional and global

[70] E.g., www.moist.it/sites/western_ionian_sea/2/SMO1/hydrophone/43
[71] This criterium excludes topics which are not properly studied and understood yet, including the biodiversity of cryptic and undescribed species, their interaction with other species and how this could be modelled.
[72] www.cbd.int

frameworks

As key elements of the European Research Area (ERA) research infrastructures are intended to be strongly integrated into European and global frameworks in order to optimise their use and exploit their full potential. ESFRI supports a respective coherent and strategic approach, which is complemented by RIs and projects not listed on the roadmap.

Global frameworks and initiatives

Sustainable and international alignments in marine research are still insufficient. The lack of international coordination is tackled by different frameworks and initiatives (see below) with regard to observations, model assimilation and users, respectively. Needs for a global framework are discussed in "A Framework for Ocean Observing"[73], prepared in the aftermath of the OceanObs'09 conference and related to GOOS.

The Global Ocean Observing System (**GOOS**) is a programme executed by IOC-UNESCO. Three GOOS Expert Panels provide scientific oversight on Physics and Climate, Biogeochemistry, and Biology and Ecosystems, and, e.g., identify the EOVs (see section C.2.2.2). GOOS has 13 GRAs, including EuroGOOS, which identify, enable, and develop sustained GOOS ocean monitoring and services to meet regional and national priorities, aligning the global goals of GOOS with the need for services and products satisfying local requirements. RIs contributing to GOOS are, e.g., EMBRC, EuroGOOS and ICOS. ICOS works closely with the global biogeochemistry community under the umbrella of the GOOS Biogeochemistry Panel (International Ocean Carbon Coordination Project, IOCCP).

The Joint Technical Commission for Oceanography and Marine Meteorology (**JCOMM**) is an intergovernmental body for the coordination of oceanographic and marine meteorological observing, data management and services. It combines the expertise and technological capabilities of WMO and IOC-UNESCO. RIs contributing to JCOMM are, e.g., EuroGOOS and Euro-Argo. Euro-Argo provides observational data to the World Meteorological Organization (**WMO**) through the Global Telecommunication System (GTS[74]) and the World Ocean Database[75]. Every Argo float is identified by its WMO number.

The Group on Earth Observations (**GEO**) is a global network/ partnership of more than 100 national governments and more than 100 Participating Organizations. GEO is advocating for informed decisions and actions for the benefit of humankind by coordinated, comprehensive and sustained Earth observations. The construction of the Global Earth Observation System of Systems (GEOSS) is a central part of GEO´s mission. GEO's global engagement priorities include supporting the UN 2030 Agenda for Sustainable Development, the Paris Climate Agreement and the Sendai Framework for Disaster Risk Reduction. The GEO initiative 'Earth Observations in Service of the 2030 Agenda' aims to support efforts to integrate Earth observations and geospatial information into national development and monitoring frameworks for the SDGs. European efforts in GEO are supported through the EuroGEOSS initiative (see below). As a network of ocean and coastal-observers, social scientists and end-user representatives from a variety of stakeholder groups, **GEO Blue Planet** is the ocean and coastal arm of GEO. During the 4th GEO Blue Planet Symposium in 2018 the increasing and pressing need for ocean information was highlighted in order to address the SDGs of the UN. The GEO Carbon and GHG Initiative (**GEO-C**) is aiming to facilitate cooperation to develop a coordinated, observation system across domains for monitoring and evaluating changes in the carbon and other cycles, and GHG emissions and to provide decision-makers with timely and reliable policy-relevant information. The most relevant policy framework for GEO-C is the Paris Agreement on Climate

[73] www.oceanobs09.net/foo/FOO_Report.pdf
[74] www.wmo.int/pages/prog/www/TEM/GTS/index_en.html
[75] www.nodc.noaa.gov/OC5/WOD/pr_wod.html

Change. Activities of ICOS in GEO-C ended recently since the orientation of GEO-C has changed towards observations by remote sensing. RIs contributing to GEO are, e.g., eLTER, EuroGOOS and ICOS.

The Global Earth Observation System of Systems (**GEOSS**) is an integrated set of coordinated, independent Earth observation, information and processing systems provided by countries and organisations within GEO. The goal is to collect and share environmental data, information and knowledge (via a single access point) with public and private sectors. So far, it comprises mainly NASA data and, particularly, remote sensing data. Nevertheless, its biggest contribution (advantage) is that it defines the best-practices in different fields of Earth observation, which were developed based on a community consensus. RIs can refer to the best-practices in order to justify their methodology.

The Intergovernmental Panel on Climate Change (**IPCC**) is an independent body founded under the auspices of WMO and the United Nations Environment Programme (UNEP). It assesses the scientific, technical and socioeconomic information relevant for the understanding of the risk of human-induced climate change. It provides comprehensive Assessment Reports, incorporating summaries for policy-makers, which are widely recognized as the most credible sources of scientific information on climate change. IPCC serves the needs of the Conference of Parties (COP) to the United Nations Framework Convention (**UNFCCC**), which develops and implements respective policy responses. The Subsidiary Body for Scientific and Technological Advice (**SBSTA**) is one of the two permanent subsidiary bodies to the Convention. It provides timely information and advice on scientific and technological matters as they relate to the Convention, its Kyoto Protocol and the Paris Agreement. In 2018, the IPCC published a special report on the impacts of global warming of 1.5°C. The scientific community is currently working on CMIP6, led by the World Climate Research Programme (**WCRP**), which will include scenarios that limit warming in 2100 to below 1.5°C relative to pre-industrial levels, and the range of impacts at the regional and local levels associated with these scenarios.

An important source of data and information for the IPCC Assessment Reports is the Global Carbon Project (**GCP**). GCP is a global research project of Future Earth and a research partner of the WCRP that integrates knowledge of GHGs from human activities and the Earth system to support policy debate and action towards a climate neutral future. Thereby, the Surface Ocean CO_2 Reference Observing Network (**SOCONET**)[76] is a volunteer group of established operators who provide openly global surface ocean CO_2 data[77]. The data is used to quantify global air-sea CO_2 fluxes and trends in surface water CO_2 levels, which are crucial to assess the global carbon balance and to monitor ocean acidification. The Surface Ocean CO_2 Atlas (**SOCAT**)[78] is a synthesis activity for quality-controlled, surface ocean fCO_2 (fugacity of carbon dioxide) observations by the international marine carbon research community (> 100 contributors). SOCAT enables the quantification of the ocean carbon sink and ocean acidification, and the evaluation of ocean biogeochemical models. The dataset is of high-quality, however, skewed towards summer. Resulting gaps can only partly be filled by Argo data. Annual datasets are provided for the Global Carbon Budget[79]. The assembled data is further used for model evaluation in IPCC and the Surface Ocean pCO2 Mapping inter-comparison (**SOCOM**)[80], providing data-based estimates of the ocean carbon sink variability. ICOS contributes to SOCONET and SOCAT, whereby ICOS data is crucial for the dataset for the Atlantic.

[76] www.aoml.noaa.gov/ocd/gcc/SOCONET
[77] Automated measurements of surface water pCO_2 and atmospheric CO_2 from ships of opportunity and moorings
[78] www.socat.info
[79] www.globalcarbonproject.org/carbonbudget
[80] www.bgc-jena.mpg.de/SOCOM

European policy drivers

Several bodies at European level agree on priorities for marine and maritime research policy[81]. The Integrated Maritime Policy (**IMP**) is a cornerstone in these policies. It aims at a more coherent approach to maritime issues and a higher degree of coordination between the different policy domains involved. The IMP integrates policy instruments in different fields such as Marine Knowledge 2020, which is considered by the EC as an important tool for centralising marine data from different sources.

The Marine Strategy Framework Directive (**MSFD**), adopted by the EU in 2008, addresses the environmental aspects of the IMP. It aims to achieve Good Environmental Status of the EU's marine waters by 2020 and to protect the resource based upon which marine-related economic and social activities depend. It represents the first EU legislative instrument related to the protection of marine biodiversity. The Blue Growth[82] concept is the long-term strategy to support sustainable growth in the marine and maritime sectors as a whole. MSFD identified four European marine regions, the Baltic Sea, the North-east Atlantic Ocean, the Mediterranean Sea and the Black Sea. They are located within the geographical boundaries of the four Regional Sea Conventions[83] (OSPAR, HELCOM, Barcelona Convention: UNEP-MAP, Bucharest Convention), through which cooperation between countries sharing the same marine waters already takes place. The regional Sea Conventions are addressed by, e.g., ICOS, JERICO-RI, EMSO ERIC.

MSFD defined eleven qualitative descriptors for the Good Environmental Status[84]. For the evaluation of the environmental status based on those descriptors the Essential Variables (see section C.2.2) are helpful. For instance, Underwater noise as part of Descriptor 11 is related to the EOV 'Ocean Sound' and is observed, e.g., by EMSO ERIC and JERICO-RI. Nevertheless, for instance marine litter (Descriptor 10) is not specifically addressed in any Essential Variable. Marine litter is studied, e.g., by AQUACOSM and JERICO-RI, however, not continuously monitored by any RI.

In the framework of its Implementation project (EMSO-Link), EMSO ERIC is working on a DG-MARE white paper on the contribution of EMSO nodes to the MSFD and on a matrix of Good Environmental Status indicators. The EMSODEV project has already outlined several indicators addressed with the EMSO Generic Instrument Module (EGIM) system, which is designed to consistently and continuously measure parameters of interest for most major science areas covered by EMSO ERIC.

European programmes and initiatives

Whereas European satellite ocean observations are widely coordinated and funded through the European Union's Earth observation programme **Copernicus**, the in situ ocean observation capacity is still fragmented and often based on a combination of national and project funding. There are several consortia and networks involved with European marine research and innovation, such as the European Marine Board (EMB). EMB operates at the interface between marine research and policy and develops common positions on research priorities for European marine research. In addition, several (thematic) partnerships between innovation and research institutes exist, including, e.g., EuroGOOS, the European Centre for information on Marine Science and Technology (EurOcean) and the European Marine Research Network (EUROMARINE).

[81] For an overview on the general policy context of the European Commission and European funding instruments for marine research see www.jpi-oceans.eu/european.
[82] https://ec.europa.eu/maritimeaffairs/policy/blue_growth_en
[83] For the European Regional Sea Conventions see http://ec.europa.eu/environment/marine/international-cooperation/regional-sea-conventions/index_en.htm.
[84] http://ec.europa.eu/environment/marine/good-environmental-status/index_en.ht

Marine institutes and research communities provide strong national capabilities and funding for ocean observations and the coordination of marine RIs. Observational research infrastructures are important in situ data sources for the European Union's Earth observation programme Copernicus. Copernicus offers information services based on satellite Earth observation, in situ data (ground-based, sea-borne or air-borne monitoring systems, as well as geospatial reference or ancillary data) and modelling. By adding value to 'raw' data produced by the data providers Copernicus develops information products to support policy-makers.

The lack of integration in European marine research is addressed by the European Ocean Observing System (**EOOS**), which is a community-driven coordinating framework for Europe's ocean observing capacity[85]. EOOS support the linking of disparate components of the ocean observing system and promote shared strategies, infrastructure development, data standardization, open access, and capacity building. A governance structure is proposed for EOOS comprising a steering group, advisory group, operations committee and funders committee.

Together with EMB, EuroGOOS is strongly engaged in building the EOOS framework. Thereby, EuroGOOS is involved in strategically important EU projects and tenders, enhancing synergies across the communities, working closely with key stakeholder initiatives and networks as well as European policy- and decision-makers. In addition, EuroGOOS co-chairs the EOOS steering group, provides an EOOS secretariat, manages EOOS communications, and ensures the link to the global operational oceanography systems and GOOS. The network of EMSO ERIC Regional Facilities represent one of the major components of EOOS. The activities carried out within the EuroGOOS EMSO Task Team are focused on both, integrating the European fixed-point observatories (both in the open and coastal ocean) and participating in EOOS. Other RIs contributing to EOOS are Euro-Argo. EUROFLEETS received a letter of support from EOOS.

EuroGEOSS is the European pillar of GEOSS and thereby the framework to combine the contributions of European GEO members. The recently started E-SHAPE project (EUROGEOSS Showcase: Applications powered by Europe) aims to set up and promote a sustainable organization dedicated to users' uptake of European EO resources. It builds on Copernicus and GEOSS through the development of co-design pilots and delivering economic, social and policy value to European citizens. Copernicus data to be utilised within EuroGEOSS will be provided through the Copernicus-DIAS.

The European Marine Observation and Data Network (**EMODnet**) is a long-term marine data initiative supported by the EU's integrated maritime policy (DG-MARE[86] for Marine Knowledge, MSFD, and Blue Growth) underpinning its Marine Knowledge 2020 strategy. The participating organisations jointly observe the sea, process the data according to international standards and offer interoperable and free data products. EMODnet covers European coastal waters, shelf seas and surrounding ocean basins. It unlocks fragmented and hidden marine data and makes them openly available, which is of importance for research communities and the public and private sectors to invest in sustainable coastal and offshore activities. SeaDataNet serves a key infrastructure for EMODnet, driving several of its portals. Furthermore, EuroGOOS is strongly involved in EMODnet, with an essential role in the EMODnet Physics portal. Thereby, the ROOS feed data into the EMODnet portal, exploiting SeaDataNet and CMEMS infrastructures and services. The portal gives access to NRT and archived data from the EuroGOOS Task Teams, including the one for Euro-Argo, which is a major in situ infrastructure for EMODnet. EuroGOOS is further partner in two EMODnet checkpoint projects in the Atlantic and the Baltic Sea, as well as in the development of the EMODnet data

[85] A strategy and implementation plan are available at www.eoos-ocean.eu.
[86] European Commission Directorate-General for Maritime Affairs and Fisheries (DG MARE), https://ec.europa.eu/info/departments/maritime-affairs-and-fisheries_en

ingestion portal. EMBRC and EMSO ERIC are streaming observational data to EMODnet, ICOS is currently in discussion with EMODnet regarding potential contributions of ICOS data products.

European projects

The H2020 project **AtlantOS** (Optimizing and Enhancing the Integrated Atlantic Ocean Observing System, 2015-2018) supported the establishment of a sustainable, efficient, and fit-for-purpose integrated Atlantic Ocean observing system and strengthened Europe´s contribution to GOOS, GEOSS, and the emerging GEO Blue Planet initiative. EuroGOOS, Euro-Argo and EMSO ERIC were involved in the project.

COLUMBUS (Monitoring, Managing and Transferring Marine and Maritime Knowledge for Sustainable Blue Growth, 2015-2018) was a H2020 project aiming to ensure that applicable knowledge generated through EU-funded projects can be transferred effectively to marine and maritime sectors. EuroGOOS was involved in the project.

The INTegrated ARctic Observation System (**INTAROS**, 2016-2021) addresses the considerable in situ data deficit in the Arctic Copernicus Services have to face. The H2020 project, which has a strong multidisciplinary focus, will help to build an efficient integrated Arctic Observation System by extending, improving and unifying existing systems in the different regions of the Arctic. The observation system will be fit-for-purpose for many Copernicus Services. EuroGOOS is involved in the project.

The H2020 project **ODYSSEA** (Operating a network of integrated observatory systems in the Mediterranean Sea, 2017-2021) will develop, operate and demonstrate an interoperable and cost-effective platform that fully integrates networks of observing and forecasting systems across the Mediterranean basin, addressing both the open sea and the coastal zone. It will support the development of a European Ocean Observing System. EuroGOOS is involved in the project.

Additional data streams and other contributions of RIs

EMBRC streams observational data to the Ocean Biogeographic Information System (OBIS[87]) and, as also eLTER, to the Open Glider Network (OGN[88]). In addition to biological data, oceanographic data often gathered as well at EMBRC stations. EMBRC contributes to the ocean sampling initiative and deployment of Augmented Observatories (e.g., Ocean Sampling Day[89]) and seeks alignment with global Genomic Standards Consortium.

Upcoming events

The following events will increase the visibility of the importance of the ocean and strengthen marine research:

For 2019, three major conferences are planned: EurOcean 2019, OceanObs'19 and OceanPredict'19[90]. EurOcean conferences are major European marine science policy conferences, providing a forum for the marine and maritime research community and wider stakeholders to interface with European and Member State policymakers and strategic planners. Since 2004, one outcome of the conferences are specific declarations[91] to raise the awareness of decision-makers for marine research priorities, which have been

[87] https://obis.org/
[88] http://wiki.glidernet.org/
[89] www.assembleplus.eu/research/ocean-sampling-day-2018
[90] 'Ocean Predict' are GODAE OceanView Symposia 'OceanPredict'19' provides insight into the latest advances in operational oceanography and requirements for ocean forecasting and services (http://oceanpredict19.org).
[91] www.euroceanconferences.eu/

critical drivers of research and policy developments in Europe since. As part of the decadal global conferences series since the 1990s, OceanObs'19[92] will bring together ocean observing communities to improve coordination of regional and national efforts to better observe the global ocean, to better respond to the joint scientific and societal needs of a fit-for-purpose ocean observing system, and maximize the overall benefit of more integrated observing.

The conferences allow marine RIs to promote their products and services and to connect further with each other and beyond. For instance, in the framework of OceanObs'19 EMSO ERIC, EMBRC, Euro-Argo, ICOS and LIFEWATCH ERIC are currently preparing a white paper[93] addressing an integrated strategy of the European marine research infrastructures for ocean observations.

In 2021 the **UN Decade of Ocean Science for Sustainable Development** will be launched to create a common framework for the sustainable development of the ocean. It is meant to provide an integrated system for science-based solutions, supporting SDG 14 and catalyse major investments in ocean science, stimulating national and regional linkage and the sustainability of GOOS. Concerns of the health of marine ecosystems, the benefits of the ocean and the need for action to protect this global resource are highlighted every year at the UN World Oceans Day (8th June).

C.3.1 Individual contributions to/ collaborations with Copernicus services

Of particular interest with regard to the marine domain are two of the six operational Copernicus services: the Copernicus Marine Environment Monitoring Service (CMEMS,)[94] and the Copernicus Climate Change Service (C3S).

With C3S, Copernicus aims to provide and visualise the ECVs defined by GCOS, and develop information about past, current and future states of the climate in Europe and globally. Products provided include

- consistent estimates of key climate variables
- global and regional reanalyses covering atmosphere, ocean, land, carbon
- data sets of past and present observations
- a near-real-time climate monitoring facility
- multi-model seasonal forecasts and
- climate projections at global and regional scales.

The major goals of C3S are the protection of citizens from climate related hazards and the improved planning of mitigation and adaptation practices. C3S requires long, high-quality and consistent data series of the ECVs which are needed to detect climatic trends of, e.g., the frequency of extreme climatic events that may have a severe impact on society. In situ data are used for climate reanalysis, as they provide essential information about the past climate, its variability and change; calibration and validation of satellite observations for the production of multi-decadal Climate Data Records with global coverage (information on many ECVs); and the evaluation and improvement of climate models by comparing model output with observations of the current and past climate, using historical forcing. C3S is implemented by the European Centre for Medium-Range Weather Forecasts on behalf of the European Commission. It is still in development and gradually including the ECVs. For the individual in situ data contributions to C3S (i.e., coverage of ECVs) by the RIs see section C.2.2.1.

[92] www.oceanobs19.net
[93] Planned to be published in the journal Frontiers in Marine Science
[94] A report providing mitigation steps to overcome risks, challenges and gaps in the contributions of RIs to Copernicus services is available here: http://eurogoos.eu/download/project_deliverables/Copernicus-2017-and-Research-Infrastructures.pdf.

CMEMS is implemented and operated by Mercator Ocean and provides oceanographic products and services for maritime safety, coastal and marine environment, climate and weather forecasting and users of marine resources. CMEMS offers more than 160 data products on the past, present and future state of the ocean derived from a combination of quality controlled in situ ocean observations, remote sensing and ocean forecast models. The products can be used for applications such as oil spill response, algal bloom forecasts, coastal inundation and wave conditions at sea, environmental assessments and climate studies. Within CMEMS, the distributed in situ Thematic Assembly Centre (INSTAC) integrates a wide variety of NRT data from six regional in situ centres. Those represent the in situ centres for each of the EuroGOOS regional systems (ROOS); i.e. the Arctic Ocean, Baltic Sea, North West Shelf, Iberia Biscay Ireland, Mediterranean Sea and the Black Sea). Additional data centres exist for sea ice, ocean colour and sea level. INSTAC is closely linked to JCOMM networks. It is one key element of the in situ data management in Europe closely linked to the major European data integration initiatives such as EMODnet Physics, EMODnet Chemistry and SeaDataNet, which are enhancing CMEMS services. INSTAC, EMODnet and SeaDataNet aim to foster open data exchange within the European marine observation community in order to close gaps in data availability.

The in situ data is collected from the major global networks (e.g., Argo, Global Ocean Surface Underway Data (GOSUD)[95], OceanSITES, Global Temperature and Salinity Profile Programme (GTSPP)[96]) completed by European data provided by EuroGOOS regional systems and national data providers. A growing quantity of in situ data is provided by RIs, highlighting their impact. In situ data are required for operational ocean forecast model validation and for longer-term reanalysis of ocean conditions over recent decades. CMEMS assesses changes in ocean heat content, temperature and salinity and produces annual Ocean Status Reports and associated Ocean Monitoring Indicators to inform marine sectors and to support policy development, supporting reports as produced by IPCC. It supports environmental assessment under the Regional Sea Conventions as well as the MSFD. DIAS (Data and Information Access Services) are a set of cloud-based platforms with central access to Copernicus data and information. Direct data flow from the RIs to DIAS is not yet operational. There are no collaborations existing or planned (yet) between Copernicus Services and AQUACOSM, ELIXIR, eLTER, LifeWatch ERIC and SIOS.

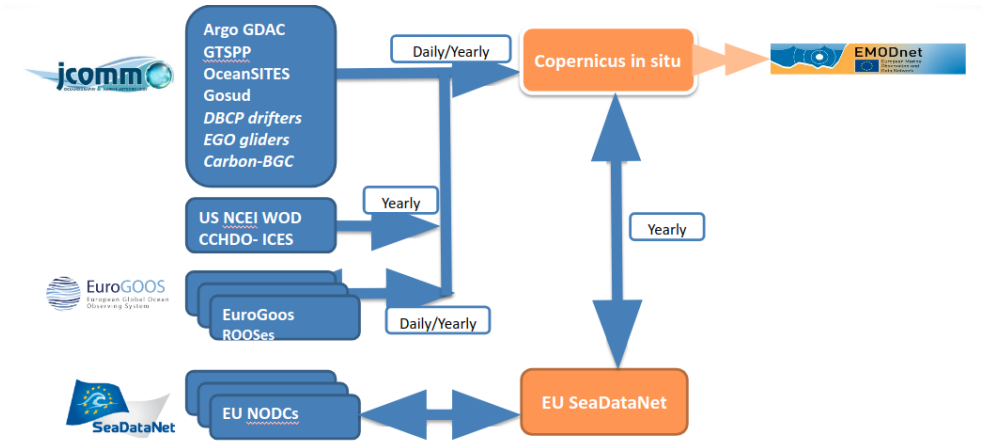


FIGURE 2: SCHEME OF DATA PROVISION IN CMEMS INSTAC (SOURCE: WWW.MARINEINSITU.EU/INTERFACES)

[95] Initiative of the International Oceanographic Data and Information Exchange (IODE) of the IOC programme
[96] www.nodc.noaa.gov/GTSPP

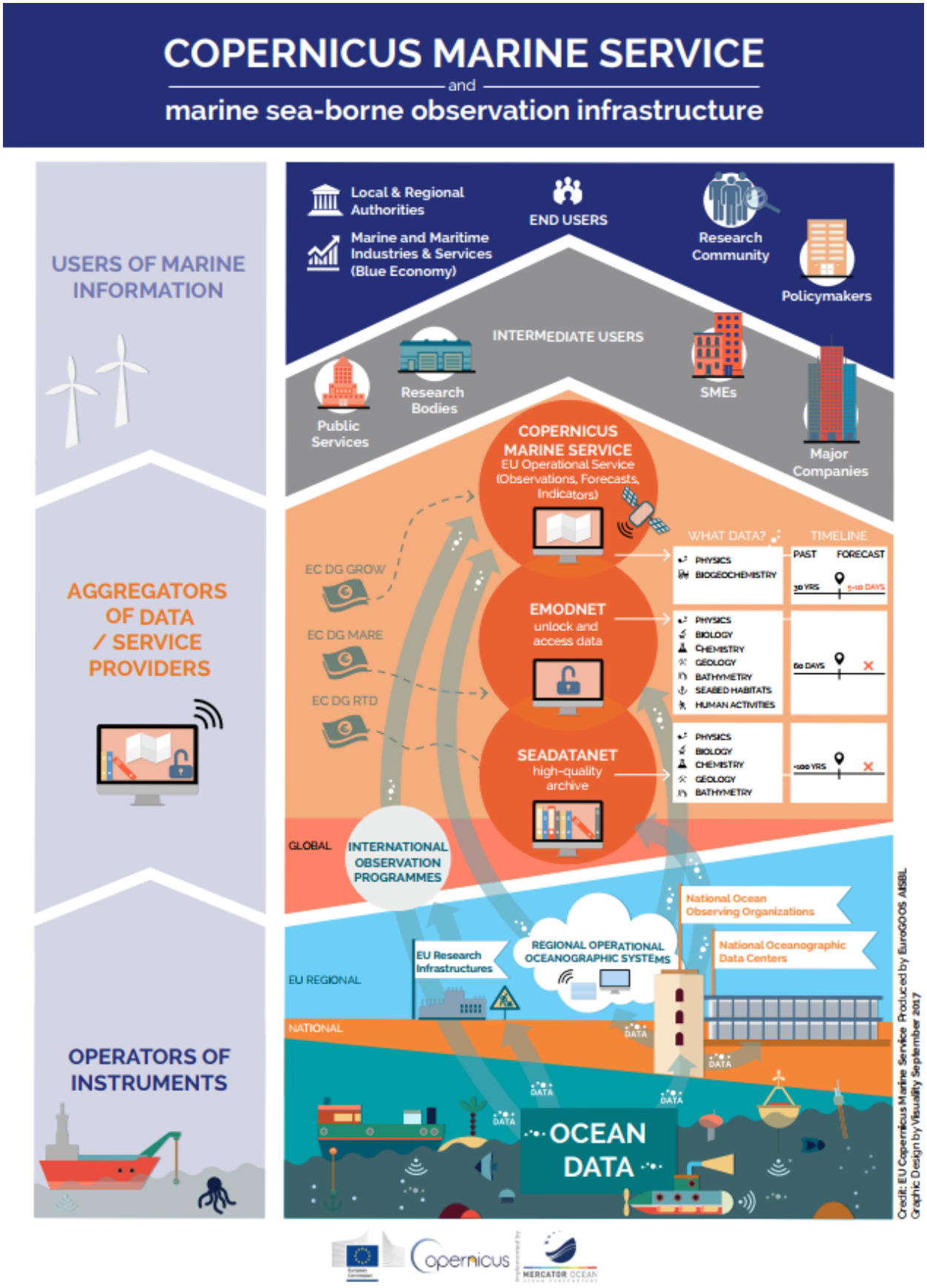


FIGURE 3: INTEGRATION OF CMEMS IN THE VALUE CHAIN OF EUROPEAN MARINE IN SITU OBSERVATIONS (SOURCE: WWW.MARINEINSITU.EU/INTERFACES/).

TABLE 18: INDIVIDUAL IN SITU DATA CONTRIBUTIONS OF RIS TO CMEMS.

RI	Individual contributions to CMEMS (e.g., in situ data)
EMBRC	- no formal link yet, however, willingness to engage with CMEMS in an open dialogue - the primarily biological EMBRC data, in many cases collected in near-shore environments, are likely to be needed for several existing or emerging Copernicus Services
EMSO ERIC	- no formal link yet, but planned to be established, as EMSO geohazard data are critical to the set-up of early warning systems and risk management in European member states - provides data to CMEMS via OceanSITES - A few Regional Facilities (PAP and Hellenic Arc) provide data to CMEMS - In the framework of EMSO-Link (WP4), EMSO ERIC will (1) plan further development of this service provision through expanding the contribution from other Regional Facilities; and (2) produce Geohazard Service workflow in order to develop EMSO seismic services.
Euro-Argo	- Euro-Argo as major (and critical) in situ infrastructure for CMEMS - provides raw data from profiling floats and reprocessed data products to CMEMS via the Coriolis data centre/ INSTAC; CMEMS assimilates the data in operational models and reanalysis products; reprocessed products that cover longer periods (> 50 years for some parameters) are planned to be provided to C3S in next phase of INSTAC - Within the H2020 project Euro-Argo-Rise the Euro-Argo ERIC plans to sign an MoU with CMEMS (as well as C3S and EMODnet)
EUROFLEETS	- no formal link yet, however, willingness to engage with CMEMS in an open dialogue and capacity to deliver data and services in due course - data collected on EUROFLEETS vessels are provided via National Oceanographic Data Centres (NODCs) and likely via SeaDataNet to CMEMS
EuroGOOS	- working with Mercator Ocean to promote the importance of integrated ocean observing and a strong connection with (intermediate) users of marine data products; includes landscape and gap analyses, and resulting action plans to close gaps in the observation system - facilitator of CMEMS INSTAC - partner in the 'Foundations' project, which delivers expert advice to the EEA supporting their role in the European in situ data coordination for the Copernicus services - one of the goals of the EuroGOOS EMSO Task team is to establish a link with relevant ongoing programmes and projects including CMEMS INSTAC (and EMODnet) and to ensure data availability via the EuroGOOS ROOS data portals and hence to CMEMS (and EMODnet)
ICOS (ocean)	- contributes data to CMEMS since phase 2 of CMEMS INSTAC
JERICO-RI	- Open dialogue with CMEMS

RI	Individual contributions to CMEMS (e.g., in situ data)
	- provides data to CMEMS via the In situ Thematic Assembly Centre - JERICO-RI data are deemed critical to CMEMS within the project at present and the visibility of these data sets to Copernicus Services is likely to increase when the Services focus on Coastal applications in the future. (- interaction planned with C3S and Copernicus Land Monitoring Service (CLMS) to complement existing activities with CMEMS) - data provided to SeaDataCloud and EMODnet are available to CMEMS
SeaDataNet	- formal link (MoU), SeaDataNet receives NRT data via INSTAC and proceeds to quality control the data to produce a best copy of the data sets that are used for climatologies in some cases used by CMEMS (provided through a Sextant catalogue and a data portal) - providing long-term archives and data management standards

CMEMS has identified in situ requirements for multi-year and NRT model and observation products[97] which could be considered by the RIs and, particularly, Euro-Argo in case of the following[98]:

- In situ data to validate all variables produced by the models (see above), for assimilation into ocean forecasts and for use in multi-year gridded products (often maps).
- Maintenance of Argo core mission (physical variables) at the present level and increased proportion of biologically equipped Argo profiling floats (Bio-Argo).
- Implementation of the Deep Ocean Observing System, in particular deep Argo floats for all relevant variables with near real-time data delivery where feasible.
- A steady increase in the number of biogeochemical measurements in European seas and globally[99].
- RT/ NRT data in the Arctic, in particular wave data.
- Enhance Argo float capabilities in the upper 10 metres of the ocean to improve models and understanding of air-sea interaction processes.

Further in situ requirements are:

- Provision of wave data and atmospheric analysis based on in situ meteorological observations to improve wave and coastal models for both circulation and biogeochemical variables.
- Provision of tidal data, more accurate bathymetric maps, river outflow data (volume, nutrients and sediments).
- Enhanced data access to member state coastal in situ observations.
- Extension of relevant in situ time series data to periods exceeding 20 years.

[97] https://insitu.copernicus.eu/FactSheets/CMEMS/

[98] See also Euro-Argo strategy https://archimer.ifremer.fr/doc/00374/48526 and the BGC science and implementation plan: http://biogeochemical-argo.org/cloud/document/science-implementation-plan/BGC-Argo_Science_Implementation_Plan.pdf; in addition http://biogeochemical-argo.org/

[99] Argo measures at an increasing number of floats dissolved oxygen, nitrate, pH, chlorophyll a, suspended particles, downwelling irradiance. The network design of BGC measurements is under discussion.

In a report on the requirements for the evolution of its in situ component[100] CMEMS mentions the goal to establish a good relationship with marine research infrastructures such as EMSO ERIC, the marine component of ICOS, and less urgently EMBRC, to have access to their data and to possibly influence their observing strategy and priorities.

C.4 Complementarities between the research infrastructures

An important prerequisite of successful collaboration and integration is to detect the complementarities between the RIs.

- DANUBIUS-RI and eLTER complement each other in their spatial coverage. While LTER Sites and LTSER Platforms range from about 1 km^2 (vast majority) to 1000 km^2 (about 50 Platforms), DANUBIUS-RI supersites are at larger scale and are located on rivers, transitional zones and coastal areas. However, the smaller spatial scale allows eLTER to investigate the ecosystem in more detail. Observations and parameters need to be harmonised to secure downstream interoperability of information produced at the facilities of both RIs.
- ICOS and DANUBIUS-RI can support each other to understand biogeochemical cycles at co-located sites (such as the Nestos Supersite in Greece), as the observations of river-sea systems by DANUBIUS-RI includes river deltas and other areas that are natural GHG emitters but presently not covered by ICOS.
- DANUBIUS-RI is the counterpart to EMSO ERIC for RSS
- Some vessel cruises coordinated by EUROFLEETS Plus involve deltas such as the Danube River Delta, signalling potential collaborations with DANUBIUS-RI.
- As most river deltas are located on active tectonic systems, EPOS and DANUBIUS-RI datasets can complement each other. Potential specific applications are discussed.
- ICOS and EMSO ERIC measure both pCO_2 in the ocean and combine their observations at co-located sites in a way that ICOS focusses on the sea surface and EMSO ERIC on the water column below. So far, ICOS is conducting the data quality control at co-located sites. Data handling of pCO_2 data should be further harmonised..
- As virtual infrastructure concentrating on biodiversity data LifeWatch ERIC is complementary with eLTER. As the provision of LifeWatch ERIC services to users depends on facilities generating in situ data including eLTER National Research Infrastructures, eLTER is a potential user of the LifeWatch ERIC e-services.
- AQUACOSM and eLTER: AQUACOSM enables to directly test a wide range of predictions from available LTER and modelling data. By conducting hypothesis driven experiments on ecosystem scale, mesocosm experimentation can contribute critical data for scenario testing and management and mitigation actions. Topics includes as Ocean Acidification, warming, pollutants, eutrophication, browning, low oxygen zones, invasive species and biodiversity effects, etc.
- EUROFLEETS Plus will play a key role to support other RIs such as EMSO ERIC, Euro-Argo, and the coordination in EuroGOOS by providing coherent and sustained time series of key environmental parameters.
- eLTER is working on a proximity analysis in the Biodiversity and Ecosystems Domain, whereby the level of proximity of pairs of RIs is determined via robust proximity indicators. Based on this analysis, potential fields of interactions will be identified as a basis for Strategic Documents of Cooperation. These proximity indicators include:
    - Co-location of in situ sites
    - Added value of joint/complementary site use and (further) design

[100] http://marine.copernicus.eu/wp-content/uploads/2019/01/CMEMS-requirements-In_Situ.pdf; for a report on requirements of all Copernicus Servicess see http://eurogoos.eu/download/project_deliverables/Copernicus-2017-In situ-State-Of-Play-Report-Observations-Data-2017-final.pdf

- Complementarity to achieve shared overall aims
- Integrated RI building strategy (national, international)
- Intercalibration, intercomparability enabling data exchange
- Necessary best practice exchange, e.g., methods, design etc.
- Shared scientific scope
- Principal nature of added value of cooperation/complementarity.

The approach was tested by a small group of RIs (eLTER, ICOS, AnaEE, Cetaf/DiSSCo, AQUACOSM), whereby strong complementarities were revealed, particularly, in the co-developing of services (e.g., semantics, metadata and site description, data flows, standards and harmonisation, and user group involvement).

- While ICOS is strongly centred on greenhouse gas measurements, the ICOS instruments, methods and data clearly synergise with eLTER. eLTER aims at a comprehensive understanding of ecosystems that includes observations of the carbon cycle and the impact of climate change on productivity or greenhouse gas emissions mainly from terrestrial but also from transitional ecosystems.
- eLTER and DiSSCo together form a robust baseline for environmental studies, by contributing to a more solid, precise and contrasted source of information on biodiversity. While eLTER provides data on selected parameters of in situ biodiversity and their site-specific historical trends, DiSSCo makes data available from scientific collections across Europe, providing taxonomic and other references of high relevance for any long-term and legacy biodiversity data and specimens.

C.5 Collaborations

C.5.1 Collaborations between the research infrastructures in the marine domain and the ENVRI cluster in general

This section includes general aspects on the collaboration between the RIs in the European ENVRI landscape and some concrete examples for collaborations between the RIs contributing to the marine domain.

Tackling the grand environmental challenges calls for comprehensive collaborations between RIs and domains in data collection and analysis and in the development of products and services. Collaboration between RIs is certainly expected by the European Commission and the national funding ministries to exploit their joint potential and enable the international scientific community to derive the full value from the investments in these large-scale environmental infrastructures.

However, it can take time to see the benefits of (early) collaboration. RIs are at risk of establishing thorough collaborations only when the RI has reached a certain level of maturity, as in the beginning it appears more important to get the RI operational and to concentrate on providing services for their own disciplines and stakeholders. However, this bears the risk of a duplication of efforts and of missing synergy effects and inefficient use of resources, hampering the contribution of RIs to a holistic understanding. Furthermore, it is getting much harder to align certain aspects when the RIs are fully established and to integrate efforts in regional and global frameworks such as EOOS, GOOS and GEO/ GEOSS.

Particularly the marine community involved in the RIs is in frequent exchange, also because the same organisations are normally involved in different RIs. Regular interdisciplinary exchange and collaboration within the marine domain and to the other domains of the environmental field are further particularly fostered by the ENVRI cluster projects. In addition, BEERi established under ENVRIPLUS has been a major forum for the cooperative work between RIs of different domains.

Apart from these projects, which were rated as very beneficial for the cluster, collaboration between the RIs was considered as insufficient. Some RIs were mentioning their wish for a better integrated RI landscape addressing the bigger picture and where the RIs represent the pillars of their respective communities.

The collaborations between RIs include:

- Common research topics
- Collaborative projects and joint thematic or training workshops
- Operational collaboration, e.g., fostering interoperability towards a service-oriented architecture
  - Development and exchange of standard parameters and methods
  - Data management (data repository, quality control, data interoperability including common ontologies, common data and software policies)
  - Joint services and products, e.g., within the projects (e.g., ENVRI, ENVRIPLUS, EOSC)
- Exchange of data (e.g. for validation, modelling)
- Integration of observations and joint use of basic infrastructures through site co-location
- Exchange of experience, e.g., on the ESFRI and ERIC processes, TNA
- Contribution to committees, advisory boards and task groups of one another
- Participation in joint expert groups
- Provision of services (e.g. chamber access for calibration, quality control of measurements)
- Technical development at experimental platforms

Closely linked to other European RIs, initiatives and projects are, for instance, JERICO-RI, EMSO ERIC and eLTER. EMSO ERIC mentioned that it would favour a shift of collaboration from bilateral (in the form of MoUs) to multi-lateral. Activities of EMSO ERIC and Euro-Argo in EuroGOOS foster the interaction within European operational oceanography, further including, e.g., the Glider networks GOSHIP and DBCP, that foster the definition of joint action topics. EMSO ERIC is connected to EPOS with regard to geophysics research on the seafloor and sub-seafloor.. The activities carried out in ENVRI-FAIR will increase the interoperability of geophysical data and metadata of EMSO ERIC and EPOS. As a multi-domain RI eLTER has intense collaborations with other RIs particularly within the terrestrial ecosystem domain. The relations of eLTER with in situ observing RIs (ICOS, SIOS, AQUACOSM, ACTRIS, AnaEE) emerge from co-location and harmonisation of parameters and methods, whereas collaboration with the generic and e-infrastructures is important, e.g., in developing semantics and data flows, management, and storage (LifeWatch ERIC, DiSSCo). Particularly, AQUACOSM aims for closer collaboration with other RIs that provide long-term data from terrestrial and freshwater (eLTER), coastal and open ocean sites (e.g., DANUBIUS-RI, JERICO-RI, EMBRC), as well as in the atmosphere (e.g., ICOS). This collaboration could bridge the connection between past-present (long-term data provided by other RIs) and future (AQUACOSM) ecosystem functioning, which could be reached most efficiently by site co-location. Collaborations could further include, e.g., AnaEE for complementarity on terrestrial experimental side. Collaborations between AQUACOSM and RIs addressing terrestrial ecosystems and the atmosphere allow a focus on less studied cross-domain interactions (physics, chemistry and biology) such as terrestrial-aquatic coupling and atmospheric-aquatic coupling. DANUBIUS-RI is currently connecting with DiSSCo and would like to collaborate further with EPOS and DREAM[101]. It is in discussion with HYDRALAB+ on integrated action, in particular on physical modelling facilities, whereby it provides data to HYDRALAB+ for physical modelling. The results are then used for numerical modelling by DANUBIUS-RI. LifeWatch ERIC is collaborating with DiSSCo and AtlantOS. SeaDataNet has links to AtlantOS. Links between JERICO-RI and ICOS exist especially with regard to carbon as one of the scientific axes of JERICO-NEXT.

[101] www.sintef.no/en/software/dream

TABLE 19: OVERVIEW ON COLLABORATIONS BETWEEN THE RIS INVOLVED IN THIS ANALYSIS. BLACK AND GREY SCRIPT INDICATE EXISTING AND PLANNED COLLABORATION, RESPECTIVELY. MOU = MEMORANDUM OF UNDERSTANDING, LOS = LETTER OF SUPPORT

		Co-location of sites													
		AQUACOSM	**DANUBIUS-RI**	**ELIXIR**	**eLTER**	**EMBRC**	**EMSO ERIC**	**Euro-Argo**	**EUROFLEETS**	**EuroGOOS**	**ICOS (ocean)**	**JERICO-RI**	**LifeWatch ERIC**	**SeaDataNet**	**SIOS (ocean)**
Collaborations	**AQUACOSM**				e.g., Stechlinsee and Lunzer See										
	DANUBIUS-RI	connecting					planned				existing (in Greece)				
	ELIXIR	potentially				Existing (France, Greece, Italy)									
	eLTER	planned	planned								- existing - Governance and business models for co-location and co-management				existing
	EMBRC	planned	connecting	linked	- Harmonization of in situ site network operation (Europe as testbed for a global issue) - Consultations, e.g., on standards and services of common interest		existing (in France)	existing (in France)			VLIZ Thornton Buoy (North Sea Data and Monitoring Time Series Station)		Existing (Belgium, Greece, Italy)		
	EMSO ERIC		Linked, EMSO ERIC is partner in DANUBIUS-RI			Linked (MoU signed)					Porcupine Abyssal Plain, (EMSO-PP: Hausgarten)	existing			(EMSO-PP: Hausgarten)
	Euro-Argo					potentially	- linked via								

		Co-location of sites													
		AQUACOSM	**DANUBIUS-RI**	**ELIXIR**	**eLTER**	**EMBRC**	**EMSO ERIC**	**Euro-Argo**	**EUROFLEETS**	**EuroGOOS**	**ICOS (ocean)**	**JERICO-RI**	**LifeWatch ERIC**	**SeaDataNet**	**SIOS (ocean)**
							EuroGOOS - Discussions with AtlantOS on interoperability of systems (techno-logical, methodo-logical, data)								
	EUROFLEETS	planned, for marine mesocosms like the mobile KOSMOS(?)				potentially	- EMSO ERIC is partner in EUROFLEETS Plus - EMSO ERIC aims to implement physical access to oceano-graphic vessels; proposing a long-term strategy of action in the EOOS of the European fleets, provided by EUROFLEETS Plus and supported by ERVO	linked			Vessels Belgica, G.O. Sars, Simon Stevin				
	EuroGOOS	planned					- MoU signed - EMSO Task team within EuroGOOS	- MoU signed - Euro-Argo Task Team within EuroGOOS - joint project AtlantOS	Letter of support						
	ICOS (ocean)	planned	planned		***Primarily at terrestrial ecosystem stations:*** *- eLTER contributes*		- ICOS conducts QC for all joint stations, EMSO ERIC wants ICOS to conduct QC for	- Euro-Argo wants ICOS to set QC standards for pH (within Copernicus) and	collaboration planned: add low cost sensor to vessels to	- ICOS provides data to EuroGOOS - less strong		Utö (ICOS atm. station)			Hausgarten

		Co-location of sites												
		AQUACOSM	**DANUBIUS-RI**	**ELIXIR**	**eLTER**	**EMBRC**	**EMSO ERIC**	**Euro-Argo**	**EUROFLEETS**	**EuroGOOS**	**ICOS (ocean)**	**JERICO-RI**	**LifeWatch ERIC**	**SeaDataNet**	**SIOS (ocean)**
					to ICOS site metadata, ICOS provides data *- LoS on in situ flux measurements* *- joint expert groups* *- Harmonization of observation parameters and methods*		all EMSO stations - Developing device to measure pCO_2	wants to validate carbon data of Argo-BGC with ICOS data	support ICOS pCO2 measurement network	linked to EuroGOOS than EMSO ERIC and Euro-Argo - more collaboration planned with regard to EOV inorganic carbon (GOOS BGC Panel)					
	JERICO-RI	planned	planned			> Streams of observational data from EMBRC to JERICO-RI > more collaboration planned	- Discussions with AtlantOS on interoperability of systems (technological, methodological, data) - sharing coastal nodes.	Joint discussions with AtlantOS and EMSO ERIC on interoperability of systems (technological, methodological, data)		- EuroGOOS is partner in JERICO-NEXT, working on science plan and data policy	- JERICO-RI wants ICOS to conduct QC of their data - exchange on carbonate observations				
	LifeWatch ERIC	potentially	planned	linked	- Long history of mutual strategic support - Integrated national teams and leading institutions - Developing services and standards, e.g. EnvThes/ EcoPortal	> Streams of observational data from EMBRC to LifeWatch ERIC > potential for closer collaboration on biodiversity related data issues (WoRMS,	- MoU signed	linked			linked	Linked			

		Co-location of sites													
		AQUACOSM	**DANUBIUS-RI**	**ELIXIR**	**eLTER**	**EMBRC**	**EMSO ERIC**	**Euro-Argo**	**EUROFLEETS**	**EuroGOOS**	**ICOS (ocean)**	**JERICO-RI**	**LifeWatch ERIC**	**SeaDataNet**	**SIOS (ocean)**
					- cooperative developments, e.g. in data management - eLTER provides semantics, LifeWatch ERIC provides services	EurOBIS, etc.)									
	SeaDataNet	potentially				potentially	- Joint participation in SeaDataCloud (Phase 2) - Data-related collaboration (EMSO ERIC provides data to SeaDataNet)	Data-related collaboration (Euro-Argo provides observational data to SeaDataNet)	Metadata related collaboration on Cruise Summary Reports	- Data-related collaboration - EuroGOOS as partner and in Advisory Board in SeaDataCloud	SeaDataNet wants ICOS data, esp. from Baltic Sea	- JERICO-RI provides data - developing system to handle coastal data			
	SIOS (ocean)	potentially													

C.5.2 Collaborations outside the ENVRI cluster and similar networks outside Europe

International collaborations are the main focus of the H2020 projects RISCAPE (European Research Infrastructures in the International Landscape) and COOP+ (Cooperation of Research Infrastructures to address global challenges in the environmental field). In RISCAPE[102] the international landscape of research infrastructures is mapped. The goal of COOP+ is to strengthen the links and coordination of EMSO ERIC, EISCAT, ICOS, LifeWatch ERIC with international counterparts (NEON, TERN, AMISR/SRI, CGSM, OOI, INPA/LBA, IMOS, ONC, AMERIFLUX, etc.). The project aims to foster international scientific cooperation and data exchange with non-EU countries and the expansion of environmental RI coordination to extra-European RIs in the sectors of marine and Arctic science.

AQUACOSM sustains the virtual network http://mesocosm.eu, which was developed within the EU project MESOAQUA as a contact point for getting information about mesocosm facilities worldwide. With this, AQUACOSM acts as a facilitator also outside the EU, e.g., in China, where several initiatives have been taken to build new mesocosm facilities. Europe, and especially Germany, has the leading role in aquatic mesocosms, only a few facilities exist in the US and on other continents.

A similar infrastructure to **DANUBIUS-RI** exists in the US. DANUIBIUS-RI in contact with similar initiatives in Argentina, Australia, China and the Mekong River Commission.

ELIXIR aims to collaborate with and support groups, organisations and initiatives such as the Global Biodiversity Information Facility (GBIF), the Group on Earth Observation Biodiversity Observation Network (GEO BON, including Marine BON), the Ocean Biogeographic Information System (OBIS) of UNESCO, and the Convention on Biological Diversity (including its Nagoya Protocol).

eLTER has links (partly via ILTER) to the International Nitrogen Initiative, the Global Land Project, FutureEarth, SAEON in South Africa, US-LTER, TERN in Australia, DataONE, the global Critical Zone Observatory community (e.g., Zones Atelier, France; TERENO, Germany; and SMEAR, Finland), and the Critical Zone network in China. eLTER will closely resemble the South African LTER, SAEON/EFTEON. eLTER cooperates with World Network of Biosphere Reserves (WNBR) of the UNESCO; and with UNECE ICP Forests in the development of standard parameters and methods. eLTER is additionally linked to, e.g., INSPIRE[103] and EUDAT[104].

EMBRC has collaborations with similar initiatives in Latin America and the Caribbean, South Africa and Chile. However, probably no equivalent infrastructure exists outside Europe.

EMSO ERIC is the European component of the global network of fixed platform ocean observatories OceanSITES**.** It has a collaboration with the Ocean Networks Canada (ONC) with the option to exchange personnel and to access to the cable observatory for testing. There are some plans to exchange some devices/ sensors at Polar seas. EMSO ERIC organises meetings with the Australian Integrated Marine observing System[105] (IMOS). EMSO ERIC streams data to PANGAEA (due to its partnership with MARUM) and Ocean Protocol[106].

[102] https://blogs.helsinki.fi/riscape-project/, particularly D3.1
[103] Infrastructure for spatial information in Europe; https://inspire.ec.europa.eu/
[104] https://eudat.eu/; eLTER contributes service specification and service uptake, and uses services as one of the main user communities. eLTER is utilising EUDAT services for searching (B2FIND) and storing (B2SHARE) of data, for which the integration into eLTER's international DEIMS database has started.
[105] http://imos.org.au
[106] https://oceanprotocol.com

Euro-Argo is deeply involved in the global Argo network, with meetings twice a year. European countries nowadays appear together instead of each country separately and maintain 25 % of the network, the US deploys 40 % of Argo floats.

EUROFLEETS has its strongest link to the International Research Ship Operator (IRSO) and its European equivalent, the European Research Vessel Operator (ERVO[107]), which is useful for implementing new approaches and deployment of new installations and systems, as well as the long-term operation and cost-efficient maintenance of existing ones. Other research vessel operators exist in the US, Canada, Greenland, Bermuda, Iceland and New Zealand offering TNA and following EUROFLEETS principles. EUROFLEETS, EU-PolarNet and ARICE (Arctic Research Icebreaker Consortium[108]) actively work on improving infrastructure development and access in the Polar Regions in cooperation with international partners.

EUROFLEETS and **EMSO** ERIC have connections to industry, in the case of EMSO ERIC, e.g., within the Smart Oceanic Cable Initiative. According to EMSO ERIC, this collaboration is not easy, especially in the case of the industry providing instruments and equipment.

EuroGOOS is one of 13 regional alliances within the GOOS and collaborates with other regional alliances through the GOOS GRA Forum, currently co-chaired by EuroGOOS. The GRAs have regular remote communication and meet in person every 2 years. The GRAs attempt to optimise the delivery of GOOS in ocean health, real time services and climate observations. EuroGOOS also works closely with Blue Planet to encourage the uptake of oceanographic services by users. EuroGOOS also works with IODE on capacity development and data management matters. EuroGOOS collaborates with the Partnership for Observing the Global Ocean (POGO). EuroGOOS plans to contribute to the UN Decade of Ocean Science from 2021 onwards.

ICOS (ocean) gathers the biggest community in Europe in its specific field and is thus an important player in many international activities. At the data level, ICOS directly supports SOCAT, and with it indirectly the Global Carbon Project, and GLODAP through the RINGO project. Furthermore, the International Oceanographic Data and Information Exchange (IODE) of IOC-UNESCO requests ICOS to merge and quality-control annual data. At the metadata level, ICOS supports the Global Ocean Acidification Observing Network (GOA-ON), which is an observing system under GOOS trying to gather the community and inform on ocean acidification. In addition, ICOS coordinates the European contribution to SOCONET and contributes to the Joint WMO-IOC Commission for Oceanography and Marine Meteorology (JCOMM), increasing the global impact of ICOS. ICOS is further involved in, e.g., EOSC, RDA and IG3IS.

JERICO-RI contributes to many international databases and is active in the exchange of best practices. Experts from the US and Australia are represented in its Advisory Board. The Northwest Association of Networked Ocean Observing Systems[109] (NANOOS), which is the regional association of the Integrated Ocean Observing System (IOOS) in the Northwest Pacific has a similar focus to JERICO-RI.

LifeWatch ERIC has intense collaborations in biodiversity and ecosystem functioning research in Europe and globally since the late 1980s. Further, it is well linked within the broader European research landscape and participates, e.g., in workshops on integrated approaches such as joint oceanographic observatories (including for instance NRT genomic data). This kind of supersites are needed to work towards a synthesis of the observations, rather than data analysis only. However, there are no such integrated stations so far.

[107] ERVO unites the operators of European research vessels
[108] https://cordis.europa.eu/project/rcn/212583/factsheet/en
[109] www.nanoos.org/education/themes/coastal_hazards.php?section=coastal_hazards_mitigation

LifeWatch ERIC is linked to SCAR, GBIF, which is harvesting data from LIFEWATCH data portal, as well as OBIS and GEO BON.

SIOS is linked to the Ny-Ålesund Science Managers Committee (NySMAC) and the Svalbard Science Forum, as well as the Canadian High Arctic Research Station (CHARS) and the Sustaining Arctic Observing Networks (SAON).

SeaDataNet establishes cooperation with large-scale ocean data management infrastructures from Europe, US and Australia to enhance interoperability between the different data infrastructures and facilitating connections to international systems such as GEOSS and the Ocean Data Portal (ODP) of the IOC-IODE programme. SeaDataNet services are used by Australian and US-American counterparts in the framework of the Oceanic Data Interoperability Platform[110] (ODIP). ODIP facilitated considerable progress in data interoperability, e.g., due to the development of common standards and the exchange of experiences with Virtual Research Environments (VREs). SeaDataNet is linked to the World Ocean Database (WOD) through its data products, and to EUDAT with regard to the Cloud environment and the HPC facilities. Data-related linkages are further established with MSFD (providing infrastructure, standardisation, data collection for several indicators, providing standardisation and validation, long-term archiving as integrator), GEOSS/ EuroGEOSS (serving with in situ data collections) and EOSC (pilot Blue Cloud).

- GCOS covers climate pillar of GOOS strategy ➔ GCOS implementation plan 2016 (includes different mapping exercises)
- GOOS: strategy 2021-2030 in work (linked to UN ocean decade (https://en.unesco.org/ocean-decade))
- EuMarineRobots

C.6 Gaps (components not covered by RIs)

- In the EOOS Conference 2018 (Brussels), some gaps in ocean observations were pointed out, among others the one in biological observations. Especially their automation, readiness, the coverage of the global scale and the provision of standardised products need to be further developed. For the latter remote sensing has only been of limited use so far, as habitats can be observed, but not taxonomy.
- Critical gaps in ocean observations, e.g., with regard to biogeochemical EOVs, hamper the ability to monitor the state of the ocean properly. In addition, the deep ocean is still largely unknown.
- The 'opportunistic' ship-based carbon observations ('ships of opportunity) are not equally distributed, as they depend on the routes of in-service ships.
- Solutions to problems (e.g. microplastics) need to be tested in dedicated test beds. These interdisciplinary and applied studies need a strong contribution of engineers. (DANUBIUS-RI)
- eLTER conducts ecosystem research in terrestrial ecosystems, transitional waters and freshwaters based on the 'whole-system approach', considering the direct societal relevance of the ecosystems and their changes. Similar ecosystem research is missing for marine ecosystems. EMBRC provides comprehensive resources for research of marine biology and ecology. However, coordinated long-term observations covering multiple aspects are not available.
- Janne: Sea ice is permeable allowing important gases that are involved in various climate feedback mechnanisms and biogeochemical processes. For example, just recently it was discovered that sea ice acts as a source of bromoform during the polar night. Earlier this process was thought to require light and thus overlooked. Now it seems that this release of bromoform, could partly explain the depleted ozone layer (Abrahamsson 2018: Organic bromine compounds produced in sea ice in Antarctic winter – Nature). Furthermore the sea ice is also a source of DMS, which acts as a Clowd

[110] www.odip.org/content/content.asp?menu=0010000_000000

condensation nuclei (Carnat et al. 2014 Journal of Geophysical Research: Oceans). The importance of Sea ice is still completely overlooked in all of the available models, even though the sea ice is one of the largest biomes on earth (van Leeuwe et al. 2018: Microalgal community structure and primary production in Arctic and Antarctic sea ice: A synthesis - Elementa). It is probably the most difficult to access and most expensive to sample and beyond available remote sensing tools.

- Gaps in the SeaDataNet database:
    - There are currently more chemical and physical than biological and geological data, as they are much easier to handle.
    - Data on natural resources only rarely available or authorisation necessary to use the data (not all data, but metadata, is openly and freely available in SeaDataNet, especially data from geoscience and aquaculture/ fisheries; SeaDataNet handles the data policies)
- AtlantOS Deliverable 1.3 www.atlantos-h2020.eu/download/deliverables/1.3%20Capacities%20and%20Gap%20analysis.pdf
- Gaps in the spatial coverage and sustainability of European observations available through EuroGOOS members:
    - Gaps in geographical distribution, mostly due to political situation in countries, gaps e.g. in Eastern Europe; plans to extend memberships of countries
    - Only about 10 % of the stations cover biological variables as e.g. chlorophyll, dissolved oxygen, plankton functional groups, Edna)
    - Less than 30% of ocean observations in Europe are funded on a sustainable basis putting the entire ocean observing system at continued risk of funding challenges.
- Gaps in Euro-Argo float network:
    - Argo network covers the ocean at varying density. The floats are sometimes not the best option for observations as it has its limitations due to measurement technique. Thus, complementary measurements (e.g. with gliders) are necessary to cover all marine areas. For example, the North Sea is a shelf area, where Argo measurements are complicated. However, some experience in shelf areas is collected with floats in the Baltic Sea)
    - Gaps also exist in the portfolio of variables, as not all sensors are appropriate to be deployed on Argo floats. For example, Pco_2 sensors are not suitable as the float would need to stop each time a measurement is taken.
- Gap analyses conducted by RIs and European programmes:
    - DANUBIUS-RI: done in 2009/2010 before DANUBIUS-RI was started
    - Elter: done during Elter H2020 project; for the research questions resulting from the horizon scanning (Musche et al., 2017: Elter D1.1, www.lter-europe.net/document-archive/elter-h2020-project-files/d01-1-horizon-scanning)
    - within H2020 project AtlantOS[111], Euro-Argo strategy for next 10 years[112] addresses identified gaps, e.g. extension of network in polar regions, higher density of BGC observations (1/4 of floats instrumented with BGC sensors)
    - Potential pilot projects were presented during EOOS conference, e.g., unlocking data such as bathymetry, or within the ERVO CTD Pilot Project (profiles of temperature, oxygen, of which many are not reported to EMODnet etc., but would be helpful for forecasting ➔ EMODnet identified 'challenge areas', where data do not exist, are not available or are not appropriate for use
    - Copernicus:
        - list of CIS^2 requirements of ocean data under development; gap analysis follows definition of requirements: missing observations, missing data, sustainability gaps, technology gaps

[111] www.atlantos-h2020.eu/download/deliverables/1.3%20Capacities%20and%20Gap%20analysis.pdf
[112] https://archimer.ifremer.fr/doc/00374/48526/51012.pdf

- Gaps in CMEMS physical observations (currents, temperature, salinity, sea level, etc.) and BGC data identified

C.7 User communities

Environmental RIs have become key players in the international research landscape, providing (new) services to support comprehensive research and to promote global integration of the research efforts for a better understanding of environmental systems, and to tackle the Grand Challenges. RIs provide the capabilities and services to produce, collect, archive and provide a comprehensive data resource, and have an important role in training and technological innovation.

- The usefulness of an RI to users other than researchers depends on how well their higher-level products and services are planned and disseminated. The observations, services and products provided by the RIs are used in the different policies of member states and also serve as long-term datasets for high-level research, adding value to the activities when planned and implemented in a coordinated manner.
- End-users of ocean observations: science, operational, public (leisure, …), policy
- Mapping of user communities e.g. by EMODnet, CMEMS
- Science users, downstream users
- Very important users: EMODnet chemistry/ physics/ biology; Copernicus
- key stakeholders in the 'triple helix' of academia, industry and the policy sectors

RI	User communities
DANUBIUS-RI	It is a major ongoing activity within the Preparatory Phase to understand the needs of the user communities and define the services and products. DANUBIUS-RI has identified five categories of user communities: - researchers - co-developers and testers - authorities - trainees - the public
ELIXIR	- Industry - Academia
EMBRC	- Industry - Scientific community, academia
EMSO ERIC	- Researchers, - Marine science researchers - Marine technology engineers - Other ERICs

RI	User communities
	- Resource managers - Policy makers - Industries - The public for both data collection and use
EUROFLEETS	- Academia - Marine Research Community - Industry - Monitoring programs
JERICO-RI	- Environment agencies, Monitoring programmes (e.g., OSPAR), other policy-makers using the data provided - Marine-based industry (e.g., oil and gas, shipping) using the facilities, expertise and data - Service providers (SMEs providing intermediate products and services) using the data - Technology providers (e.g., sensor developers) conducting proof-of-concept, verification and demonstration of technologies - Other RIs, initiatives - Marine research community
SIOS	- Scientific community

C.8 Portfolio of services and products

- Who is providing which services? e.g., ICOS is providing post-processing of pH, pCO2 data
- RIs can be characterised according to their data life cycle (see ENVRIPLUS D5.1)
- RIs have an important role in training/ education and technological innovation
- AQUACOSM: elaborated data products under development
- ELIXIR: provides training to life science professionals to deal with the exponential growth of bioinformatics tools and data, and to fill the training gap left by transformative data technologies in medicine and the life sciences, including how Big Data are generated, analysed and interpreted
- Coastal intelligence: understand, manage and prevent coastal degradation
- eLTER:
    - co-designed tools:
        - DEIMS (site and data catalogue)
        - EnvThes (controlled vocabulary)
    - In collaboration with industry (planned or existing): (i) joint development of sensors, automated sampling systems, telemetry, (ii) calibration/validation of remote sensing products (iii) development of field kits for use in remote places/extreme weather conditions (e.g. battery technology, solar and wind powered kit, weatherproofing of equipment), (iv) development of field recording software (both on land and in water), (v) materials testing (i.e. exposing material, e.g. building materials, to the environment at a site where weather

and air chemistry data are available)

- EMBRC: elaborated products currently in discussion, but EMBRC is primarily producing data
- EMSO ERIC:
    - technological development, e.g. EGIM (EMSO Generic Instrument Model; developed within EMSODEV) for measurements of temperature, conductivity, pressure, dissolved O2, turbidity, ocean currents, passive acoustics, (salinity?) ➔ prototypes will soon be tested; collaborating at the level of Smart Oceanic Cable Initiative (Bruce M. Howe, SOEST, UH Mānoa)
    - FixO3 produced a handbook of best practices, but this is only a starting point of a "living" document, which evolves over time/ should be updated every x years; this process should be coordinated by one organisation, rather than collecting all manuals of different sources in one repository (which is especially for newbies very confusing); the organisation could be e.g. EMSO ERIC, or EuroGOOS (neither OceanSITES[113] nor EOOS do have own funding)
- SeaDataNet: SeaDataCloud is currently developing a Virtual Research Environments (VREs) operating in the cloud:
    - Users will be able to combine SeaDataNet data and their own data
    - Under development in SeaDataCloud project, which focusses on services
- EUROFLEETS: education: dedicated WP in EUROFLEETS Plus; floating universities, ocean literacy in schools etc
- AQUACOSM: will provide 11500 TA-access person days before Dec 2020, in addition to cross-domain training/capacity building, interoperability and technological advancement.
- Euro-Argo: Elaborated products by the (Euro-)Argo community
- LifeWatch ERIC:
    - Marine data archaeology:
        - Interest in specific region; identification of data sources; contacting authorities and requesting copy
        - Follows a protocol (www.lifewatch.be/en/marine-data-archeology-strategy)
        - (Apart from Flanders Marine Institute) one of the leading partners for this task is the Hellenic Centre for Marine Research
    - VREs:
        - LIFEWATCH ERIC offers MicroCT service, facilitating remote access to specimen e.g. for taxonomic studies; specimen do not have to be sent/ shipped (www.lifewatchgreece.eu/?q=content/microct-services)
- Measurement technologies: concept ➔ pilot ➔ mature
- Euro-Argo provides real-time data for operational users and delayed mode data for climate change research and monitoring

[113] www.oceansites.org

TABLE 20: SERVICES AND PRODUCTS PROVIDED BY THE RIS IN THE MARINE DOMAIN.

RI	Category	Service/ product
DANUBIUS-RI		While still work in progress, DANUBIUS-RI is currently developing more than 300 services under the following categories: - digital and non-digital data - methods, tools and expert support - study and measurements - diagnostic and impact - solution developments - tests, audit, validation and certification - training services
EMBRC	Access	- Access to highly divers ecosystems, from polar habitats to coral ecosystems, for in situ experimentation, monitoring, and sampling (i.e. research vessels, scientific diving); - Access to marine biodiversity: collected wild types from local habitats, cultured model organisms (vertebrate, invertebrate, plant), microbial culture collections; - Access to modular experimental systems, technological platforms and associated analytical platforms and e-infrastructure (e.g. imaging, metabolomics, screening) enabling researchers to work on-site with all tools and facilities for their research;
	TNA	- Access clearance and facilitated procedures for researchers to marine genetic resources in compliance with the Nagoya Protocol and Access and Benefit sharing regulations; Access to EMBRC/marine stations through H2020 project ASSEMBLE+ (www.assembleplus.eu/access/transnational-access)

RI	Category	Service/ product
EMSO ERIC	Access	- TNA - Virtual access
	Training	Training plan and activities
	Hub- single entry point to:	- Science services - Engineering and logistics services (EMSO Generic Instrument Model was developed as product within EU project EMSODEV - Data services - Communication services - Innovation services
	Standardisation and quality	Best practices and EMSO label
Euro-Argo	Data	All the data access means are described at www.argodatamgt.org/Access-to-data 1. For machine to machine services, Argo data are available through APIs such as Thredds and ERDDAP: • GDAC FTP servers at Coriolis : ftp://ftp.ifremer.fr/ifremer/argo and US GODAE: ftp://usgodae.org/pub/outgoing/argo • http://tds0.ifremer.fr/thredds/catalog/CORIOLIS-ARGO-GDAC-OBS/catalog.html • www.ifremer.fr/erddap 2. Human data discovery and subsetting is provided in the GUI (Graphic User Interface) • www.argodatamgt.org/Access-to-data/Argo-data-selection 3. Coming soon : GDAC data subscription turning into operation the ENVRIPLUS use case.

RI	Category	Service/ product
EUROFLEETS	Access	- TNA with standardised application system
	Training	Training programs for emerging scientists , technicians Outreach material for general public
	Other	- New Tools and software for deep sea research - Analysis of and recommendations for long term sustainability - Provision of European Vessel Database[114]
JERICO-RI	Access	- Virtual access to data and related services - TNA
	JRA	- 6 applied projects (to demonstrate added value of JERICO-NEXT)
	Standardisation	- Development of best practices and the JERICO-RI Label
SIOS (Atmosphere)	Other	Infrastructure Optimisation (consulting on how to build an arctic RI)
	Data Hub	Multidisciplinary; no own database, but is harvesting from others; No elaborated data products yet, maybe satellite data products specifically for Svalbard in the future
	Training	Training programmes, workshops
	Access	Access, logistics

[114] www.rvinfobase.eurocean.org/eurofleets/index.jsp

C.9 Citizen science experience

The term 'citizen science' describes the involvement of members of the public in scientific research activities, e.g., the creation of research questions, the collection and analysis of data or volunteer computing. The principles of citizen science are provided, e.g., by the European Citizen Science Association (ECSA[115]). The potential and added value of citizen science depends on the field and is increasingly discussed in research and innovation policy, and requested by the European Commission in Horizon 2020. Environmental science is among the most favourable fields to conduct citizen science due to the general interest of the public in environmental topics. In turn, getting the public involved raises the general awareness of environmental problems. The inclusion of citizen science as a tool in environmental RIs could have great potential in ecological and biodiversity research as mentioned in the ESFRI Roadmap 2018 and already applied by LifeWatch ERIC. As a member of ECSA LifeWatch-Italy has many activities going on with regard to the inclusion of citizen science in their portfolio. However, citizen science can be very valuable for spatially and/ or temporally dense observations or sampling in remote areas (as done, e.g., in the Volvo Ocean Race 2017/18[116]). In turn, RIs could represent suitable formal support structures for citizen science, which are not sufficiently developed.

The Euro-Argo RI doesn't really have Citizen Science activities. But the RI collaborated with the civil society for floats deployment from

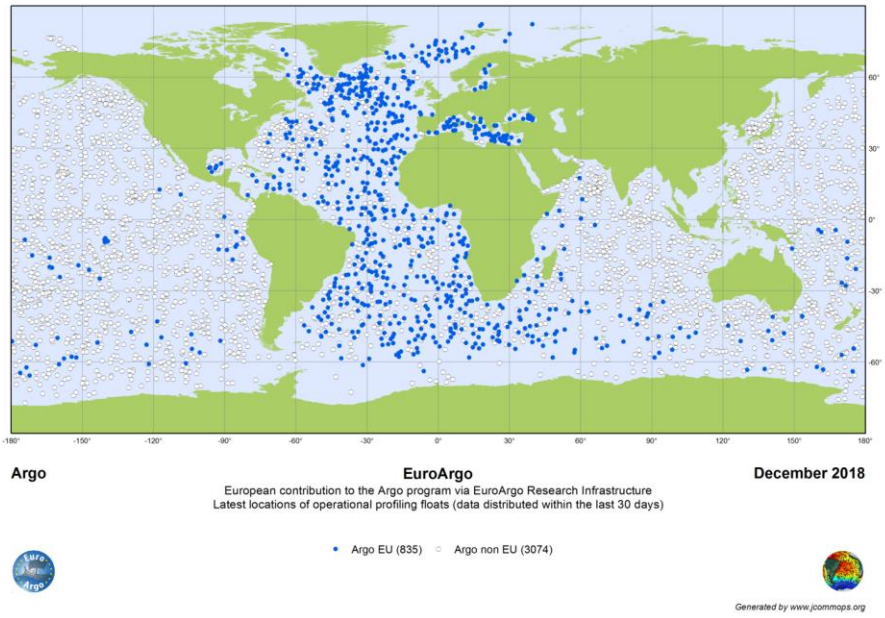
- sailboat www.coriolis.eu.org/content/download/19500/126117/file/Contribution%20de%20navires%20d'opportunit%C3%A9%20au%20projet%20Coriolis%20-%20french.pdf in French
- or industrial www.euro-argo.eu/News-Meetings/News/Latest-News/Partnership-between-Euro-Argo-and-Orange-Marine
- or navy www.coriolis.eu.org/content/download/15829/103442/file/Cols-Bleus-2999.pdf

C.10 Station/ facility locations

- Euro-Argo: in Nov. 2018 globally 1,073 floats measuring BGC in addition ➔ strong European involvement (but still far from global coverage)
- eLTER: hierarchical and modular structure of site categories: eLTSER Platforms, eLTER Sites (Master Sites, Regular Sites, Satellite Sites); European LTER sites and national networks have mainly been developed bottom-up. The sites collated in DEIMS (different provenances with about 450 original LTER sites and about 35 CZOs) have mostly been established for different monitoring and research purposes. They are heterogeneous in terms of the investigated ecosystem type, scale of investigation, complexity, and instrumentation. Individual sites measure a wide range of biotic and abiotic variables according to site-specific requirements (the site´s "ecological profile") and often following site-specific standards for instrumentation and protocols. ➔ common agreement on the need to harmonise, coordinate and synthesise ➔ one of the key challenges for the development of the infrastructure ➔ To tackle this challenge, the provision of standardised top-down mechanisms and benchmarks to produce the comparable baseline data is of central importance. Such a standardised basic observation scheme needs to integrate requirements of several research communities and domains (ecosystem, critical zone, biodiversity, socio-ecology, hydrology). In addition, it needs to be founded on accepted scientific frameworks. ➔ planned to have system-focused and integrated observation schemes and assign them to the Ecosystem Integrity and the Essential Biodiversity Variables framework (Haase et al. 2017).

[115] https://ecsa.citizen-science.net/sites/default/files/ecsa_ten_principles_of_citizen_science.pdf
[116] https://archive.theoceanrace.com/en/news/11939_Making-sustainability-the-bedrock-of-a-global-sporting-event.html

- ICOS OTC: requirements for data: to follow SOPs, but some flexibility (e.g. with regard to calibration), as otherwise much less participation ➔ OTC is trying to improve the data within ICOS, as this is more realistic than waiting until the data is improved outside
- Data quality in SeaDataNet is not as high as e.g. in ICOS, as less scientific use but rather industrial data use
- EMSO ERIC: 8 regional facilities, 3 test sites located from the North Atlantic through the Mediterranean Sea to the Black Sea
- EUROFLEETS: vessel list available
- Euro-Argo:
    - Argo is a network of 4000 platforms that die after a certain time (2-5 years) and in between do profile down to 2000 m for the majority and 4000 to 6000 m for the deep ones every 10 days and in between they drift according to the current at their parlink depth. The only thing we can give is their last location See www.euro-argo.eu/Activities/Data-Management/Access-to-data or JCOMMOPS



C.11 National memberships in RIs

The national participation in RIs differs strongly between the European countries. Several countries, including France, Germany, UK and Spain, are involved in one way or another in all or at least most RIs included in this analysis. It is evident that the participation of, particularly, small countries and countries in South-Eastern and Eastern Europe is lower, which might reflect the differences in the funding capacity, especially for research. Environmental RIs are not always in the focus of national RI roadmaps of countries having limited financial means (e.g., Baltic States). In addition, the participation of a country in a RI might be hindered or delayed by the national roadmap processes if they exist, as they are related to the political commitment and financial support (from national sources) needed.

The development of national roadmaps for RIs is not mandatory but encouraged by the European Commission, as ESFRI orients towards the prioritisation of RIs within the national roadmaps. The national roadmaps should be aligned to the National European Research Area (ERA) Roadmap, which is in turn mandatory. National roadmaps follow different approaches and goals, and their importance varies between countries. The H2020 project InRoad[117] gives recommendations to harmonise and synchronise

[117] for the results see www.inroad.eu (Publications)

the national roadmap processes within Europe, including priority-setting, funding and lifecycle management of Research Infrastructures, by exchanging best practices among the main stakeholders of EU Member States, Associated Countries and at European level.

The most recent versions of half of the national roadmaps (total n=25) are older than 4 years (2014 and earlier). In most countries, the national roadmaps are revised every four to six years and their development is detached from the ESFRI roadmap process and not harmonised in terms of procedures, rules and budget thresholds (see Deliverable 12.3, Kutsch et al., 2018), which would, however, be very beneficial. For several countries a revision is due (e.g., Poland, Romania, UK). National roadmaps often focus on national RIs and the participation in those pan-European RIs, that are ESFRI Projects or Landmarks. The national participation is of particular interest for those RIs providing a network of distributed long-term observations and aiming for pan-European spatial coverage, particularly, ICOS and eLTER.

For eLTER it is a big challenge to get 44 national networks coordinated for the ESFRI process.

Many of the institutes that contributed to the precursors projects of EMSO ERIC (Esonet-NoE, EMSO-PP, FixO3) are now Regional stations to EMSO ERIC, although there are still some countries pending membership as, e.g., Germany and Norway, which already has requested explicit support to become full member during 2019.

LifeWatch ERIC is an important RI on many national roadmaps. LifeWatch-Greece supports the development of other RIs (e.g., EMBRC) by sharing experience on the technology, e.g. by providing working examples, upon which the other RIs can build.

The Finnish Marine Research Infrastructure (FINMARI[118]) combines all major components of the Finnish marine research community. It is a distributed infrastructure network of field stations, research vessels and multi-purpose icebreakers, laboratory facilities, ferryboxes, fixed measurement platforms and buoys. FINMARI, coordinated by SYKE, allies research infrastructure of four Finnish research institutes, three universities, and a state-owned shipping company. The joint infrastructure development plan is based on addressing the multiscale variability of the marine environment through synergetic integration of the research foci of the partnership. Poland is planning to establish a similar national RI for coordinated ocean observations.

[118] www.finmari-infrastructure.fi/; for the international integration of FINMARI see: www.finmari-infrastructure.fi/international-co-operation

TABLE 11: NATIONAL PARTICIPATION/ NATIONAL INSTITUTES INVOLVED IN DIFFERENT RIS (AS OF 24 JANUARY 2019), HOST' MEANS THAT THE COORDINATING INSTITUTE IS IN THE RESPECTIVE COUNTRY. NON-EU-28 COUNTRIES WITHOUT ANY PARTICIPATION ARE NOT LISTED HERE. EEO = ESTONIAN ENVIRONMENTAL OBSERVATORY

Country	Year(s) of publication	Mentioned in national roadmap	AQUA-COSM	DANU-BIUS-RI	ELIXIR	eLTER	EMBRC	EMSO ERIC	Euro-Argo	EURO-FLEETS	Euro-GOOS	ICOS	JERICO-RI	Life-Watch	SeaData-Net	SIOS
EU-28 members																
Austria	2014	ELIXIR	x	x, e		x1, x2 (host)								p		
Belgium	Under preparation				x		x			x1, x2, x3	x (host)	x, @	x1, x2	x, p	x1, x2, x3	
Bulgaria	2010, 2017	DANUBIUS-RI, Euro-Argo, EMSO ERIC, EUROFLEETS, JERICO-RI, SeaDataNet		x, e		x1, x2			x	x1, x2			x2		x1, x2, x3	
Croatia	2014									x1, x2	x				x1, x2, x3	
Cyprus	Under preparation				x										x1, x2, x3	
Czech Republic	2010, 2015	ELXIR, ICOS		x, e	x	x2						x				
Denmark	2011, 2015	ELIXIR, ICOS	x		x					x1, x2, x3	x	x	x1	p	x1, x2, x3	
Estonia	2014	ELIXIR		x	x					x1, x2, x3	x	h			x1, x2, x3	
Finland	2014	ELIXIR, Euro-Argo, ICOS, LifeWatch	x	e	x	x1, x2			x	x3	x	x (host)	x1, x2	o, p	x1, x2, x3	x

Country	Year(s) of publication	Mentioned in national roadmap	AQUA-COSM	DANU-BIUS-RI	ELIXIR	eLTER	EMBRC	EMSO ERIC	Euro-Argo	EURO-FLEETS	Euro-GOOS	ICOS	JERICO-RI	Life-Watch	SeaData-Net	SIOS
		ERIC, SIOS														
France	2008, 2012, 2016	ELIXIR, eLTER, EMSO ERIC; Euro-Argo, ICOS	x	x, e	x	x2	x (host)	x, p	x (host)	x1, x2, x3	x	x, @	x1 (host), x2 (host)	o, p	x1, x2, x3 (host)	x
Germany	2013	ICOS	x (host)	x, c	x	x1, x2		p, h	x	x1, x2, x3	x	x, @	x1, x2	p	x1, x2, x3	x
Greece	2014	ELIXIR, EMBRC/ Lifewatch ERIC, Euro-Argo, EMSO ERIC, ICOS, JERICO-RI	x	x, c	x	x2	x	x, p	x	x1, x2, x3	x	h	x1, x2	x, p	x1, x2, x3	
Hungary	2018			x, c	X	x1, x2						h		o, p		
Ireland	2007			x, c	x			x, p	x	x1, x2, x3 (host)	x	p, h	x2		x1, x2, x3	
Italy	2011, 2017*	ELIXIR, EMBRC, EMSO ERIC, ICOS, LifeWatch ERIC		x, c	x	x1 (host), x2	x	x (host), p	x	x1, x2, x3	x	x, @	x1, x2	x, p	x1, x2, x3	x
Latvia	-					x2									x1, x2, x3	
Lithuania	2011, 2015	(ELIXIR and EMBRC mentioned in		e		x1									x1, x2	

Country	Year(s) of publication	Mentioned in national roadmap	AQUA-COSM	DANU-BIUS-RI	ELIXIR	eLTER	EMBRC	EMSO ERIC	Euro-Argo	EURO-FLEETS	Euro-GOOS	ICOS	JERICO-RI	Life-Watch	SeaData-Net	SIOS
		roadmap)														
Luxembourg	-				x											
Malta	-												x1, x2		x1, x2, x3	
Poland	2014*	Euro-Argo, ICOS		e		x1, x2			o	x1, x2, x3	x	p, h	X1	p	x1, x2, x3	x
Portugal	2014	EMSO ERIC, EMBRC, Euro-Argo, ICOS, LifeWatch ERIC	x		x	x2	x	x, p	(x)	x1, x2, x3	x	p, h	x1, x2	x, p	x1, x2, x3	
Romania	2008	LifeWatch ERIC		x, e (host)		x1, x2		x		x1, x2, x3		h		x, p	x1, x2, x3	
Slovakia	-					x2								o, p		
Slovenia	2011, 2016	eLTER, ELIXIR, LifeWatch ERIC			x	x2					x			o, p	x1, x2, x3	
Spain	2013	EMSO ERIC, Euro-Argo, LifeWatch ERIC	x	x, c	x	x1, x2	x	x, p	x	x1, x2, x3	x	p, h	x1, x2	x, p	x1, x2, x3	
Sweden	2015	ELIXIR, EMBRC, EMSO ERIC, Euro-Argo, ICOS,			x	x1, x2		p		x1, x2, x3	x	x, @	x1, x2	o, p	x1, x2, x3	x

Country	Year(s) of publication	Mentioned in national roadmap	AQUA-COSM	DANU-BIUS-RI	ELIXIR	eLTER	EMBRC	EMSO ERIC	Euro-Argo	EURO-FLEETS	Euro-GOOS	ICOS	JERICO-RI	Life-Watch	SeaData-Net	SIOS
		LifeWatch, SIOS														
The Netherlands	2008, 2013, 2016	ELIXIR, ICOS, LifeWatch ERIC	x	x, c	x	x2		p	x	x1, x2, x3	x	x	x1, x2	x (host), p	x1, x2, x3	x
The United Kingdom	2010, 2012	ELIXIR, ICOS		x, c	x (host)	x2	x	x, p	x	x1, x3	x	x, @	x1, x2	p	x1, x2, x3	x
Non-EU-28 members																
Albania															N, 2	
Belarus	-															
Faeroe Islands										x1, x2, x3						
Iceland	-									x3					x1, x2, x3	
Moldova				x, c												
Montenegro	2015														x2	
Norway	2012, 2016	ELIXIR, EMBRC, Euro-Argo, ICOS, SIOS	x	e	x		x	p	x	x1, x2, x3	x	x, @	x1, x2	p, s	x1, x2, x3	x (host)
Russia	-														x1, x2, x3	
Serbia				e		x2										
Switzerland	2015	ELIXIR, ICOS	x	e	x							o				

Country	Year(s) of publication	Mentioned in national roadmap	AQUA-COSM	DANU-BIUS-RI	ELIXIR	eLTER	EMBRC	EMSO ERIC	Euro-Argo	EURO-FLEETS	Euro-GOOS	ICOS	JERICO-RI	Life-Watch	SeaData-Net	SIOS
Ukraine	-			x, e											x1, x2, x3	

*Roadmap not available in English

Legend:

x = Full members/ in consortium

(x) = Planned full member

o = Observers

p = Partner in PP project (but not in ERIC, if appropriate)

s = Stakeholder from other countries

AQUACOSM: + Turkey

DANUBIUS-RI: c = commitments (funding or political), e = Expressions of interest and support

ELIXIR: + Israel

eLTER: x1 = EnvEurope (2010-2013), x2 = eLTER (2015-2019, + Israel)

EMBRC: + Israel

EMSO ERIC: INFRADEV project EMSODEV

EUROFLEETS: x1 = Eurofleets1 (2009-2013, + Greenland, Turkey), x2 = Eurofleets2 (2013-2017, + Greenland, Turkey), 3 = EUROFLEETS Plus (2019-2023, + Canada, Greenland, Turkey, New Zealand, US)

ICOS: h = Participation in a H2020 INFRADEV project RINGO (2017-2020) as country potentially joining the ERIC, @ = hosting an ICOS ocean station

JERICO-RI: x1 = JERICO (2011-2015), x2 = JERICO-NEXT (2015-2019)

LifeWatch ERIC: + Turkey (as partner in PP project)

SeaDataNet: x1 = SeaDataNet (2006-2011, + Algeria, Georgia, Israel, Lebanon, Morocco, Tunisia, Turkey)

x2 = SeaDataNet 2 (2011-2015, + Algeria, Georgia, Israel, Morocco, Tunisia, Turkey)

x3 = SeaDataCloud (2016-2020, + Georgia, Israel, Turkey)

SIOS: + Japan

C.12 Data management

- One-stop shops/ single entry points are discussed frequently and the EOSChub is a start in this direction. However, the further away from operational oceanography, the more complex it gets to integrate data in one database/ to manage data and user interfaces are very hard to define for all fields. Several access points can be beneficial, even Copernicus has several.
- The origin of data is often not clear to the users when they get the data from the big data bases (= black holes). This needs better policy by European Commission.
- European Commission invested heavily in data aggregation systems (resulting in well-resourced projects such as e.g. EMODnet, but at the national level the systems are not well-resourced, so that data streams to European data bases are hampered
- The observations of several RIs are streamed to EMODnet (EMBRC, EMSO ERIC, ICOS, JERICO-RI, LifeWatch ERIC) and SeaDataNet (seeTable 19).
- Following protocols is essential for interoperability, as machines need to understand and combine information given; fast data harvesting impossible without standards.
- Data management itself can be easily be optimised. More important is to make sure we are measuring the right variables, i.e. work towards 'fit-for-purpose' needed.

RI	Data repository and streams, interoperability
AQUACOSM	- Licence of data currently discussed - Will follow FAIR data principles - Data management procedures are under development - Metadata delivered immediately to a data base (WP4, Wageningen), data later (embargos!)
DANUBIUS-RI	- Nodes and Supersites are responsible for the acquisition of data - Data available through the Data Centre portal - Collected data stored in the Data Centre - Data will follow FAIR data principles - Data management is based on standards in the respective fields (e.g INSPIRE Directive) and under development - Adherence as far as possible to international measurement protocols - Data Policy aims to open exchange of data, metadata and elaborated data products - Data processing services, modelling standardization guidelines
ELIXIR	- One of the forerunners with regard to FAIR data principles - encourages the life science community to adopt standardised file formats, metadata, vocabularies and stable and unique identifiers

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654182

	- The standards are generally defined by the community. It is not the role of ELIXIR to mandate the use of one particular format or standard, rather ELIXIR tries to curate the standards available (e.g., through FAIRsharing[119] and work with communities that are actively promoting data interoperability and reproducible research. > Examples: - Common Workflow Language (www.commonwl.org), which was used by the ELIXIR Marine Metagenomics Community for the description of metagenomics analysis pipelines to increase their transparency and reproducibility - collaboration with Biocontainers[120] to support community efforts on bioinformatics software deployment methods
eLTER	- local data services, cloud data services, partner data services (e.g., TERENO; network data nodes) ➔ data integration portal (data visualisation and access services) ➔ (Standard web data service) - data repository: EUDAT (B2SHARE)? - Development of the eLTER Data Integration Portal (eLTER DIP) within eLTER project to (1) integrate standard web-based data services from eLTER Data Nodes (e.g. WMS and SOS), (2) allow advanced data providers to register and maintain their own data and metadata links, and (3) enable end-users to discover, view and access integrated data from all data nodes - DEIMS site and dataset catalogue provides a key service to unambiguously document long term observation sites and in situ facilities, and link this to dataset documentation and discovery services - Creating a software suite for eLTER Data Nodes by use of standard Web services
EMBRC	- Public databases - Follows FAIR data principles - fosters open publications - Using standards for data management as far as possible - Own and international measurement protocols
EMSO ERIC	- New data portal (MooDA-based) in development, currently in prototype phase (ready before summer 2019), own data and external data will be provided and the additional service of online data QC will be offered - Data licences (as key of being operational): need to be agreed soon between EMSO ERIC, countries and institutes - Standards from OceanSites

[119] http://fairsharing.org

[120] see ELIXIR Implementation Study on Biocontainers: www.elixir-europe.org/about-us/implementation-studies/biocontainers-2018

Euro-Argo	- see www.argo.ucsd.edu/Argo_data_and.html - Data is openly and freely available within 24h - Monthly snapshots of data basis are labelled with DOIs - Following standards given by Argo global network - Working closely with other Research infrastructure and JCOMM networks to define common set of mandatory metadata and vocabularies[121] - The inclusion of new variables (e.g., BGC) is challenging, e.g. in terms of QA/QC, as there are e.g. no reference data for statistics available and instruments are typically not recovered from the sea - Argo uses SeaDataNet vocabulary as most marine institutes in Europe as well as the CF Conventions and Metadata - All data is provided to the Argo international global data centres (www.argodatamgt.org/Access-to-data), they are archived at the US NODC operated by NCEI; all Argo data is provided within 12h on GTS on the two Argo Global Data Centres managed by Ifremer and US-GODAE
EUROFLEETS	- TNA data transferred to British Oceanographic Data Centre (BODC) - EUROFLEETS contributes to open data pilot (EOSC) - Most data openly available (maybe with embargo)? - Automated data streams etc. in development - European Virtual Infrastructure in Ocean Research (EVIOR) will be further developed - EUROFLEETS provides data to central data bases
EuroGOOS	- data was quite strict licenced in early 2000s, but this licence was not carried to the AISBL; is on to-do list and will most probably be: open data without embargos and based on IOC policy - INSTAC and EMODnet metadata catalogues offers overview on available data
ICOS	- data storage and provision in ICOS Carbon Portal - using PIDs (persistent identifiers) ➔ will be standard also for other RIs? (discussion in ENVRI-FAIR) - Metadata based on ontology: Semantic web (WEB 3.0) - Open linked data - GOOGLE Dataset Search beta launched ➔ ICOS data will be linked there soon - Data links can be harvested

[121] www.atlantos-h2020.eu/download/deliverables/7.1%20Data%20Harmonization%20Report.pdf

	- goal: making data streams operational - data directly streamed to global databases (instead via intermediate European databases) - BODC vocabulary for (meta)data - SOPs including QC as community effort, which produces common trust, facilitating interoperability - challenging is the establishing of the (NRT) data flow (annual data flow at the moment) - No standard QC and no proper communication of the QC procedure in physical oceanography; ocean domain benefits remarkably from FAIR data principles - A challenge is to reach and sustain a sufficient level of standardisation of the observations between the national networks.
JERICO-RI	- Challenges for data interoperability especially for biodiversity/ biological data (for physical data rather easy): emerging sensors/ systems producing images, but how to work with this data (in a standardised way)? - different archives for different scientific fields; the goals is to keep the data integrated (instead of splitting and feeding them into different data bases) and to make it as simple as possible for the data user; the approach how to do this is discussed in a dedicated WP in JERICO-NEXT and the following project - all RIs should work together towards an interoperable data management (metrology, standards/ homogeneity, uncertainty; e.g. recent workshop with the goal to organise a metrology lab network (where national metrology institutes are involved)
LifeWatch ERIC	- Data also available in OBIS and EMODnet (accessible data) and stored in IPT (archived data), CC licenced - Data flows and vocabulary: EUNIS habitats, EUROBIS, OBIS, GBIF, WORMS, marineregions.org, NERC (BODC NERC vocabularies), Darwin Core (terms) - Data standardisation: OBIS event data - National nodes are responsible for the acquisition of data - LIFEWATCH ERIC data management is based on standards common in the respective field - Simple Object Access Protocols (SOAP), Runtime Application Self-Protection (RASP) - Spatial data: INSPIRE (https://inspire.ec.europa.eu/), Open Geospatial Consortium (OGC, www.opengeospatial.org/standards) - Biodiversity data: e.g. Ocean Biogeographic Information System (OBIS, www.iobis.org/) - Vocabulary: e.g. World Register of Marine Species (WoRMS), European Ocean Biogeographic Information System (EurOBIS) - Versioning of datasets with DOIs

	- Results are available to the scientists working in the virtual labs, but not openly available yet - LIFEWTACH is working on data repository, one option for the management would be the "Docker" system (containerization), which facilitates easy repetition of analysis - data licences handled individually in each country node, in marine domain either CC BY or CC0
SeaDataNet	-represents an archive - Most of the French marine data managers in SeaDataNet/ SeaDataCloud ODATIS-cluster (www.odatis-ocean.fr/en/about-us/what-is-the-odatis-ocean-cluster/) - French data managers develop metadata catalogues for earth observation systems which is of importance for ENVRI community (ENVRIfair) - Adapting ISO and OGC standards and achieving INSPIRE compliance - has data policy and licences - Uses also other vocabularies apart from its own
SIOS	

C.12.1 Data interoperability

Data interoperability is key for (interdisciplinary) collaboration and an efficient use of diverse data in order to address the grand environmental challenges. Complete data interoperability consists of schematic, syntactic and semantic interoperability (Hugo, 2009). Each RI is working on its internal data interoperability, e.g., by introducing metadata standards. Particularly for networks of experimental platforms and focusing on physical access, for which standardisation of measurements is limited, it is of utmost importance to have thorough and standardised metadata to make sure that the data produced can be understood and used by others.

Semantic interoperability paves the way for accurate and reliable communication and exchange. It requires agreement on common ontologies, vocabularies, metadata standards and frameworks such as 'Essential Variables' (OOPC 2015).

The ENVRI community has a strong interest to improve the (data) interoperability between the different RIs in order to simplify future collaborations. The ENVRI Reference Model, which was developed and further improved within the EU projects ENVRI and ENVRIPLUS, serves as a community standard to help the RIs achieve better interoperability between their heterogeneous resources, particularly with regard to data and services. The ENVRI Reference Model is originally based on the experience gathered by several research infrastructures. It is particularly helpful for those that are in the planning/construction phase.

Still remaining challenges related to data interoperability (between the RIs and beyond) are addressed within the H2020 project ENVRI-FAIR. However, only ESFRI-listed RIs and SIOS (which was still on the ESFRI roadmap during the proposal) are participating in the project. The project excludes all other RIs even though for them data interoperability is no less important, including IS-ENES, which is as a modelling RI strongly dependent on observational data and respective FAIR principles. SeaDataNet will contribute

experiences of its own FAIR maturity to the project and also represent Copernicus in the project. It seeks for a closer cooperation and connectivity with the RIs.

An analysis of the data interoperability of the RIs involved in ENVRI-FAIR is provided within ACTRIS-2 WP5 (D5.4)[122].

ENVRI-FAIR is the second-biggest cluster project in the EU-call for the European Open Science Cloud (EOSC). Its overarching goal is the implementation of FAIR (Findable, Accessible, Interoperable, Re-usable) data principles in the ENVRI cluster (on cluster level, domain level and RI level) and establishing the connection to the European Open Science Cloud (EOSC). Within ENVRI-FAIR, the RIs will work on the FAIRness and quality of their data based on candidate Essential Variables and develop FAIR services, which will be demonstrated by use cases. As part of the project, the landscape is mapped with regard to, e.g., existing data policies. The main focus lies on implementation and further development of services at RI and domain levels, while ensuring the highest possible level of standardisation for each domain. In the project the technical preconditions will be established for the implementation of a virtual, federated machine-to-machine interface to access environmental data and services (service point) provided by the contributing ENVRIs, called the ENVRI-hub.

D. Implications for future collaboration and further integration

This section is meant to identify potentials for increased collaboration and integration in order to address the Grand Challenges jointly and thus more effectively. While each RI addresses individual scientific questions, combining the expertise and output provided by the RIs allows to answer scientific questions which are beyond the capabilities of the single RIs, e.g., by combining observations at different altitudes. The further identification of gaps will also provide an important contribution to identifying potential joint research topics in the future. It is expected that enormous resources would be unlocked and the common impact would drastically improve if mutual scientific approaches and common services could be realised.

D.1 Potentials for joint research topics

During the interviews the following potential joint topics were identified:

- For the Physical variables: Climate Change monitoring, Ocean temperature and heat content, Ocean salinity and freshwater content, Steric sea level, Ocean circulation, process studies, ocean modelling.
- For the Biogeochemical variables: ocean carbon uptake, oxygen minimum zones and nitrate cycling, ocean acidification, biological carbon pump, phytoplankton communities, satellite ocean colour validation, ocean management.
- For Biodiversity variables: several RI have internal Biodiversity Communities (eLTER, DiSSCo, LifeWatch, EMBRC, ELIXIR, etc.), that need to be fully engaged and connected with other relevant ENVRIs and beyond Europe.
- Integrated approaches should be developed with regard to societal initiatives towards oceans e.g. the UN Decade of Ocean Science for Sustainable Development (2021-2030). RIs should make use of and contribute to these initiatives with common science-driven approaches.
- Exchange of experience with citizen science
- Continuous dialogue on technological development necessary
- Thematical:

[122] www.actris.eu/Portals/46/Documentation/actris2/Deliverables/public/WP5_D5.4_M49.pdf?ver=2018-06-07-094718-377

  - Extending observations of biogeochemical and biological variables (challenges for data interoperability) ➔ very urgent to monitor, understand how the environment is reacting to changes, e.g. how far species tolerate changes and what happens if certain threshold is reached
  - Fostering multidisciplinary/ integrated approaches
  - Changes in scientific practice towards big data synthesis
  - Covering important topics such as eutrophication and microplastics ➔ need for test beds for solutions (strong involvement of engineering)
  - Automation of observations
- Services for science:
  - Development of joint VREs
  - Joint offers for TNA
  - Coordinated contributions to international initiatives, databases
- Data interoperability is seen as a continuous community effort to be continued in ENVRI-FAIR
  - Common data policies, licences
  - Versioning of datasets
  - NRT data streams
  - Joint efforts to close gaps in spatial coverage, e.g. by co-location of sites and "special offers"
- Documented scientific priorities:
  - The Euro-Argo scientific priorities: https://archimer.ifremer.fr/doc/00374/48526/
  - The ICOS strategy: www.icos-ri.eu

D.2 Potentials for joint fit-for-purpose services and products

The goal is to further develop the output of the RIs from separately providing access to facilities and research data towards synergetic products and services.

- Copernicus Marine Service: all the Marine domain RI provide quality-controlled data to the In Situ thematic centre of CMEMS both in NRT for forecast and in delayed mode for reanalysis. *(see attached PPT for the list of variables)*
    - Needs of CMEMS INSTAC for their product catalogue: new types of platforms and variables to be included:
      - NRT data (updated hourly)
        - Data on currents ➔ adding HF radar planned for 2019 (JERICO-RI/ EuroGOOS contributing?)
        - carbon (BGC) data ➔ planned by CMEMS for 2019 (Euro-Argo, ICOS, EMSO contributing?)
      - (Based on data of those new platform types/ variables:) Reprocessed multi-year data (updated every 6 months)
        - Currents ➔ adding VM-ADCP 2020 HF radar planned for 2019
        - carbon data ➔ planned for 2019
      - based on those reprocessed multi-year data, ocean monitoring indicators can be derived (updated every 6 months), e.g.:
        - based on data on currents: Mediterranean outflow planned for 2019

        ➔ new activity of CMEMS that starts in close link to the EC´s Ocean State Report
  - C3S also use the CMEMS INSTAC product for reanalysis
- Euro-Argo:
  - There are already joint products that are produced within CMEMS from ENVRI RIs (Euro-Argo, ICOS, EMSO ERIC, Gliders, EUMETNET drifters, Jerico, Eurofleet campaign data through

SeaDataNet, EuroGOOS) www.marineinsitu.eu/dashboard/ for the latest 30 days of data http://marine.copernicus.eu/services-portfolio/access-to-products/ for the complete catalogue
    - There is also a service provided by Coriolis French program which has been developed in the past 20 years www.coriolis.eu.org/Data-Products/Data-Delivery/Data-selection
    - These products are also shared with EMODNET www.emodnet-physics.eu/Portal
    - Within ENVRI-FAIR these products will be enhanced in particular biogeochemical variables in links with EMODnet but also envisage for some biology variables such as plankton with EMODnet-biology
- Increasing Service-orientation ➔ working towards more sustainable systems which satisfy users´ needs (stakeholder engagement!) ➔ "Fitness for purpose" ➔ at the moment about 25 % of data gathered on sustainable basis… should be 100 %!)
- EOSC was mentioned as good example that the classification of RIs in specific domains is not necessarily needed. Barriers of data usage need to be unlocked and services can be provided jointly, e.g., within the ENVRI cluster projects.
- Joint data usage, e.g. for computational models (NEMO (www.nemo-ocean.eu/), MEDUSA), would be very beneficial to get a broader picture, however, this kind of collaboration is not very efficient at the moment ➔ no day-to-day collaboration needed, but data interoperability; engaging the modelling community is quite challenging
- Increasing automation in marine domain, as ship-time is extremely expensive ➔ Elegant automated solutions for observations (robotics)
- Cluster of RIs can provide shared solutions
- Need to consider the private sector in data provision and usage ➔ data as key enabling blue growth/ economy
- address the challenges and requirements of the Copernicus Services (see http://eurogoos.eu/download/project_deliverables/Copernicus-2017-and-Research-Infrastructures.pdf; https://insitu.copernicus.eu/library/reports/WorkshopDocumentEvolutionoftheCopernicusInSituComponentWorkshop25April2018Final.pdf
- Sustainable blue economy conference in Kenya Nov 2018; OECD highlights blue economy (global awareness is rising on policy level, but not in people´s minds)
- Characteristics of best data products:
    - Realistic and relevant (fit-for-purpose, convenience for user not supplier)
    - Clear/ concise (jargon-free, including provenance)
    - Usable (accessible, processible)
- In EOOS conference Quillon Harpham discussed the need of indicators to evaluate data products, which would help to know beforehand what to expect ➔ which parameters/ phenomena available?, what is spatial and temporal coverage? Am I licenced to use the data commercially? (e.g., industrial users)
- Copernicus in discussion with industry, e.g., on list of variables which is needed by industry and on data accuracy (industry is willing to pay for relevant information/ data, to make operation more efficient and cheaper) ➔ but: industrial funding difficult (not very realistic) as different (most often lower) accuracy needed by industry than for science ➔ won't pay for high-accuracy measurements
- From OceanObs'19 Abstract:
    - Novel technology developments (RIs as driving force for promoting engagement with sensor development companies, decommission offshore platforms and blue ocean strategy business)
    - Coherent and sustained time-series of key environmental parameters (EVs?) ➔ multiparametric integration of observations on environmental platforms ➔ high level of cooperation is established with European and international research vessel operators,

through ERVO and IRSO group ➔ useful for implementing new approaches and deployment of new installations and systems, their long-term operation and cost-efficient maintenance of existing ones ➔ EUROFLEETS will play key role to support other RIs such as EMSO ERIC, Euro-Argo, and the coordination in EuroGOOS)
    - Education and training of researchers to increase European skills base
    - Communication to the general public on events such as volcanic risks, seismic risks, poor air quality as well as information on biodiversity impacts
    - "big data" from space-based and in situ observations as key driver for the development of new services promoting activities in the private sector
    - Accurate data and the scientific and technical knowledge that will underpin and construct tools for decision-making and development of efficient regulations and policies/ machine learning techniques for sensor data analyses
    - + strengthening linkages with Joint Programming Initiatives (JPIs), and other initiatives such as EMODnet, EEA Copenhagen and INSPIRE Directive
- AQUACOSM: MESOAQUA was coordinated by University of Bergen, Norway that have run their mesocosm facility since 1978, where many years of successful Transnational Access (TA) was provided, well before the expression was coined); Such activity based on various funding could be an option for other ENVRIs/ projects/ networks which do not have explicit TA funding by EU (EU has role as catalyst of collaboration).
- eLTER:
    - fostering interoperability by cooperation towards a service-oriented architecture for which the LifeWatch Reference Model may serve as guidance;
    - development of joint demand-driven data discovery and mobilisation plans involving eLTER NRIs and LifeWatch National Centres;
- Potential joint proposals
- Potentials for co-location of sites
- Collaborations for instance on a practical level in the form of co-located sites, however, collaborations are not always easy, as each RI has specific requirements regarding the sharing platforms
- benefits of co-location of sites and super site concept, which is especially important for less studied cross-domain interactions, such as e.g. terrestrial-aquatic coupling, atmospheric-aquatic coupling.
- ENVRI plus co-location and inter-operational approach between different Research Infrastructures, specifically at the Master Sites.
- AQUACOSM:
    - Further Co-location with on-going long term, including LTER sites where possible
    - Co-location in marine mesocosms is not trivial, permanent structures are not presently possible but with the seagoing mesocosms in AQUACOSM, dynamic placement of experimental facility based on need is foreseen. Using the KOSMOS mesocosm (Kiel, www.aquacosm.eu/mesocosm/kosmos-kiel-off-shore-mesocosms-for-ocean-simulations/):
        - Worldwide only open-water mesocosm
        - Mobile station, which is ready for collaboration ➔ temporary co-location possible (e.g. with LTER, ICOS (gas exchange) or EMBRC stations)
        - Studies:
            - E.g. CO_2 tests in 2001, 2003 and 2005
            - Recently: deep low oxygen zones
    - In addition, a lower cost "AQUACOSM" pelagic mesocosm is under development, to meet some of the needs in less exposed waters.
- DANUBIUS-RI: Potentially further site co-location (consider that DANUBIUS-RI Supersites are large-scale sites that together cover the river-sea continuum)

- EMBRC: There is potential for more co-location! ➔ co-location increases analytical potential and offers access to technology which would not have been available otherwise ➔ great opportunities for EMBRC community
- eLTER/ ICOS/ …: Promoting Cooperative Master Sites in the National Networks of ICOS and eLTER (see also D12.3): This will bring clear and significant additional scientific value in the form of comprehensive and systematic observations, common data evaluation and modelling approaches by our user communities, as well as a possibility to explore ways of reducing construction and operational costs (example: TERENO)
- ICOS – EMSO ERIC: co-location is natural, new sites should be co-located if possible, could also existing ones be extended? ➔ at least EMSO should be able to measure also at the surface
- Conceptual and technical developments
- Recently discussed in JERICO-RI ➔ the community is willing to co-locate (in order to connect different observation networks to answer multidisciplinary questions), however, super-sites alone would not be sufficient (EuroGOOS)
- Multi-use of infrastructure initiative since 2013 (experiences from JPI Oceans pilot actions) ➔ the idea is to use existing monitoring programmes for expansion to cover additional indicators in a flexible and cost-efficient way ➔ general agreement that it was a good idea, but not very successful, as parameters for equipment cost savings and efficiencies not visible and have not been the drivers/ many loose ends and disconnected actors/ different steering and governance needed for systemic change/ etc.
- Joint memberships, common data centres?

D.3 Implications on governance for the RIs in the marine domain

- Refer to sustainability plan (D17.5) and ENVRI strategy discussed in BEERi: agreed on common direction of RIs towards consortium agreement (in progress), coordinated funding and communication strategy
- Data interoperability: RIs wish to get it operational, not just demonstrated in pilots
- One-stop-shop for all RIs practically not realisable (huge amounts of data, too different data types, it will take the user forever to find something), rather linkage to different data repositories through respective data portals
- Existing RIs should extend their portfolio and emerging RIs should be designed according to the gaps identified.
- The currently most important task for many of the RIs is to get (fully) operational. ➔ But shouldn´t intense collaboration start immediately and before all RIs are 100 % mature? (avoiding reconfiguration which might be necessary later)
- check which RIs could work together to minimize conflicts for site PIs which RI they will join ➔ governance models
- Avoid competition for country contributions by developing incentives for countries participation in multiple RIs
- Exchange and transfer knowledge to countries which are less experienced with RI contributions etc.
- Intensive exchange on results of ENVRI-FAIR (e.g., in BEERi), which is restricted to ESFRI-listed RIs + SIOS, to increase FAIRness also in other RIs
- AQUACOSM suggests that the potential consolidations should be based on scientific complementarity ➔ It should be in the focus which science units are needed rather than keeping ENVRIs as individual systems ➔ Consolidation of data handlers/ data bases (as NSF in USA) would be beneficial
- One of the key Pan-European requirements concerning environmental in situ RIs relates to coverage of the continent´s environmental gradients. This includes not only environmental and geographic gradients (altitude, climate, hydrology, geology, soils), but also social and economic gradients within environmental zones. (eLTER)

- EMBRC: staying relevant in terms of its key topics (fit-for-purpose); in a better integrated RI landscape with more collaboration addressing the bigger picture (more holistic approach) and where the RIs represent the pillars of their respective communities
- Greece is interested in joining the ocean domain
- EC is positive about a coordination body for ENVRIs as discussed in BEERi strategy WS in Riga
- It would be more straightforward if carbon measurements in ocean (marine domain) are in one hand (so far ICOS is responsible for surface measurements, EMSO ERIC for water columns below) ➔ but e.g. ICOS is missing most of the variables explaining the concentrations and fluxes(?)
- Projects (primarily run by huge national institutes) distract sustainability goal of RIs
- eLTER: ICOS and eLTER have started working on a pilot strengthening of such options, including exploring possibilities for co-enhancing their RIs by a clear division of tasks, and mutually complementing their site networks across the current geographical coverage of each partner. Currently, the most feasible option for a starting point of discussions appears to be the in-depth cooperation of structurally independent entities. This approach would build on the existing infrastructures and deepen the existing cooperation in co-location, methodological standardisation and data interoperability that has already started in ENVRIPLUS. Platforms such as GEOSS could be used for common metadata catalogues. This option would not require large organisational changes of either ICOS or eLTER. […] The main disadvantage, namely insufficient coverage across Europe of each of them with ongoing competition on membership (on the European level) and resources (on the national level), could be tackled by a novel generation of smart agreements towards European RI integration: The vision could be, that the "ICOS module" as part of eLTER RI´s "whole system approach" is compliant and taken care of by ICOS, either as a formal ICOS site or via association with ICOS. Mutually, focal components of eLTER (complementary biogeochemical cycles components, less intensive approaches for assessing carbon budgets at larger scales or Regular Sites, biodiversity, socio-ecology) covered at ICOS sites could be formal or associated eLTER sites. This field needs further clear descriptions of scientific, methodological and technical core competences of the single research infrastructures in order to avoid duplication of effort.
- eLTER: core task is the harmonisation of standard variables
- European Commission expects consolidations of ENVRIs, however, the countries are driving the process (membership fees)
- Overcome institutional and personal visibility needs ➔ "from egosystems to ecosystems" (Joaquin …, EOOS conference) ➔ leadership needed for integration (by EC?, e.g., by EOOS)
- Supply-driven (instrument-driven) to demand-driven (variable-driven) observations ➔ who is most important user community?
- Cross-calibration done on basis of overlaps between observing systems!
- promoting the participation of European countries in several RIs

E. Conclusions and outlook

- European culture of cooperation/ inclusiveness is exceptional compared to other regions of the world (where it´s more competitive and less open science focused, e.g. US) ➔ expected and forced by EU funding agencies ➔ common legal frameworks of EU are of great advantage ➔ not the case e.g. in Africa, therefore much more difficult to have an efficient governance and funding
- Summarise scientific fields with potential for increased collaborations, options for further integration
- Coming back to integration of ENVRI into regional and global frameworks
- RIs important for routine inclusion of emerging technology into marine monitoring and to adopt a holistic observing strategy
- European RIs are well-placed to bring the G7 "Future of Seas and Oceans" strategy forward

Appendix

A – List of interview partners

Interviews were conducted with the following core people of the RIs:

RI	Name
AQUACOSM	Jens Nejstgaard
DANUBIUS-RI	Adrian Stanica
ELIXIR	Annalisa Milano
eLTER RI	Michael Mirtl
EMBRC	Nicolas Pade
EMSO ERIC	Juanjo Dañobeitia
	Richard Lampitt
Euro-Argo	Sylvie Pouliquen
EUROFLEETS	Aodhan Fitzgerald
EuroGOOS	Glenn Nolan
ICOS	Benjamin Pfeil
JERICO-RI	Laurent Delauney
	Patrick Farcy
	Ingrid Puillat
LifeWatch ERIC	Christos Arvanitidis
SeaDataNet	Michèle Fichaut
	Gilbert Maudire
SIOS	Heikki Lihavainen

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Acronyms and abbreviations

Research infrastructure acronyms

ACTRIS	Aerosol, Clouds and Trace Gases Research Infrastructure
ARISE	Atmospheric Dynamics Research InfraStructure in Europe
EISCAT_3D	European Incoherent Scatter Scientific Association – 3D
EUFAR	European Fleet for Airborne Research
EUROCHAMP	-
HEMERA	-
IAGOS	In-Service Aircraft for a Global Observing System
ICOS	Integrated Carbon Observation System
IS-ENES	Infrastructure for the European Network for Earth System Modelling
SIOS	Svalbard Integrated Arctic Earth Observing System

Other acronyms and abbreviations

AERONET	Aerosol Robotic Network
AISBL	Association internationale sans but lucrative (International non-profit Association under Belgian Law)
BEERi	Board of European Environmental Research Infrastructures
C3S	Copernicus Climate Change Service
CAMS	Copernicus Atmosphere Monitoring System
CMIP	Coupled Model Intercomparison Project
CORDEX	Coordinated Regional Climate Downscaling Experiment
CTBT	Comprehensive Nuclear-Test-Ban Treaty
DIAS	Data and Information Access Service
EBV	Essential Biodiversity Variable
EC	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasts
ECV	Essential Carbon Variable
ENES	European Network for Earth System Modelling
ENVRI	Environmental Research Infrastructure
EOSC	European Open Science Cloud
EOV	Essential Ocean Variable

ERA	European Research Area
ERIC	European Research Infrastructure Consortium
ESFRI	European Strategy Forum on Research Infrastructures
EU	European Union
FAIR	Findable, Accessible, Interoperable, Re-usable
GAW	Global Atmosphere Watch
GC	Grand Challenge
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GHG	Greenhouse gas
H2020	Horizon 2020
IA	Integrating Activity
ICAO	International Civil Aviation Organization
ICSU	International Council for Science
IMS	International Monitoring System
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
IRIS	Incorporated Research Institutions for Seismology
ISR	Incoherent Scatter Radar
JRA	Joint Research Activity
LIDAR	Light Detection and Ranging
MACC	Monitoring Atmospheric Composition and Climate
NDACC	Network for the Detection of Atmospheric Composition Changes
NDMC	Network for the Detection of Mesopause Changes
NRC	National Research Council
NRT	Near Real-Time
PP	Preparatory phase
RI	Research infrastructure
RRT	Real Real-Time

RT	Real-Time
SAG	Scientific Advisory Group
SDG	Sustainable Development Goal
SOP	Standard operating procedure
TCCON	Total Carbon Column Observing Network
TNA	Transnational access
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
UTLS	Upper troposphere–lower stratosphere
VOC	Volatile organic compound
WCC	World Calibration Centre
WCRP	World Climate Research Programme
WDC	World Data Centre
WIS	WMO Information System
WMO	World Meteorological Organization