Towards interoperable transatlantic environmental research infrastructure system
- A COOPEUS Research Infrastructure Roadmap
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Project title: Strengthening the cooperation between the US and the EU in the field of environmental research infrastructures

Project acronym: COOPEUS

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1. Introduction

1.1 Background

Environmental research is addressing challenges relating to the dynamics of our planet, such as climate change, biodiversity, carbon emissions, and natural and man induced hazards crossing borders between scientific disciplines and nations. Due to the global nature of these challenges, the scale and complexity of the resources needed, and the development of information and communication technology, there is a necessity to develop a greater international collaboration in research and knowledge sharing. Research infrastructures (RI) by offering research services for the wide user groups and by developing new world-class research environments for the users, are key instruments for advancing the production and cross-usage of scientific information, knowledge and technologies.

COOPEUS (*Strengthening the cooperation between the US and the EU in the field of environmental research infrastructures*) is a EC funded coordination and support action project that brings together Europe's major environmental research infrastructure projects within ESFRI (European Strategy Forum on Research Infrastructures), i.e. EISCAT, EPOS, LifeWatch, EMSO, and ICOS, with their US counterparts that are responsible for the NSF funded research infrastructure/cyber-projects such as AMISR, EARTHSCOPE, DataONE, OOI and NEON (the list of Acronyms is in the Appendix 1). The aim of COOPEUS is to provide a platform for initiating collaborative cross-research infrastructure work and for developing common plans. The table below describes the scientific fields of COOPEUS and lists the EU and US research infrastructures directly participating in the COOPEUS activities.

Table 1. The scientific fields of COOPEUS and the EU and US research infrastructures involved in the COOPEUS activities.

Space Weather	EISCAT - The European Incoherent Scatter Scientific Association AMISR - Advanced Modular Incoherent Scatter Radar
Carbon observations	ICOS – Integrated Carbon Observation System NEON - The National Ecological Observatory Network Oak Ridge NL DAAC, DataONE – Data repository, Oak Ridge DAAC node
Biodiversity	LifeWatch - European e-Science Infrastructure for Biodiversity and Ecosystem Research NEON - The National Ecological Observatory Network DataONE - Data Observation Network for Earth
Ocean observations	EMSO - European multidisciplinary seafloor and water column observatory OOI - Ocean Observatories Initiative DataONE - Data repository, Network for Earth/Partnership for Interdisciplinary Studies of Coastal Oceans
Solid Earth Observations	UNAVCO - A non-profit university-governed consortium, facilitates geoscience research and education using geodesy EPOS - European Plate Observing System IRIS - Incorporated Research Institutions for Seismology EARTHSCOPE - A community conducts research across the Earth sciences utilizing data from instruments that measure motions of the Earth's surface, record seismic waves, and recover rock samples from depths at which earthquakes originate

1.2 The purpose of the COOPEUS roadmap document

The common COOPEUS roadmap document is defining the joint objectives and actions for the future COOPEUS collaboration. In general, the strategic visioning process with the future planning of common actions helps COOPEUS partners to enhance the common understanding of these joint activities and clarifies the scope of the joint actions. Strategic roadmap process also supports the communication both within the COOPEUS community and outside the COOPEUS community by development of coherent, common message towards users, stakeholders and other interest groups that are following the community actions. Clear vision together with well-defined actions helps also partners to target the efforts, resources and work in the collaborative community activities.

The COOPEUS roadmap document formulates the RI community-driven vision and proposes collaborative actions for the next 10 years for COOPEUS partners as the COOPEUS community aims to enhance research infrastructure collaboration between EU and US in the environmental field also beyond the EC project lifetime and beyond EU-US collaboration.

The structure of this document, similarly to many other forward-looking strategic documents, has three elements: evaluation, actions and vision (Fig 1). Each of these elements where the subject of multiple meetings, outreach efforts and community engagements during the roadmap process. The COOPEUS document outlines the current transatlantic research infrastructure landscape in the field of environmental sciences, the common mission for the 2025, and main action topics to achieve the set mission.

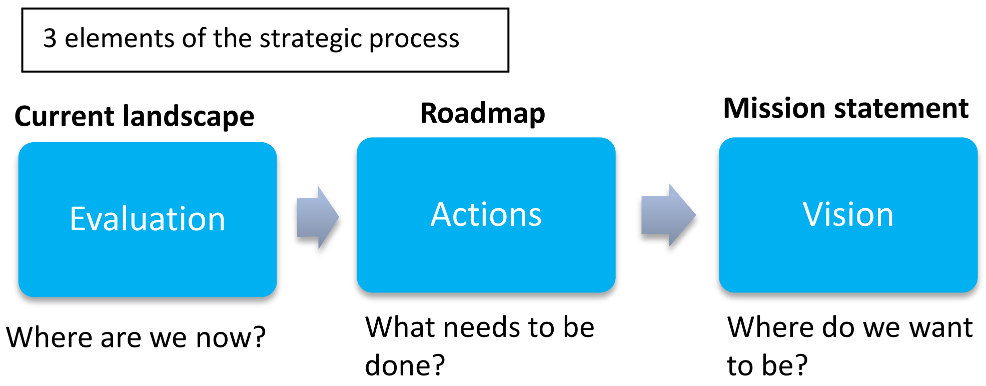


Figure 1. Three elements of the strategic process with the listing of COOPEUS roadmap parts (in bold).

1.3 Drafting process of the document

The draft of the COOPEUS research infrastructure roadmap has been developed among the COOPEUS partners from both sides of the continents and the topics presented in this document have been discussed and processed in the sequence of dedicated roadmap planning workshops. The roadmap process takes into account—and builds upon of all the direct and indirect COOPEUS activities since its inception.

So far, the COOPEUS Work Package 8 has organized three dedicated roadmap workshops. The first workshop was organized in conjunction of the COOPEUS Annual meeting 2014. The workshop was held at Hyytiälä Forestry Station in Finland, in September 2014. The Hyytiälä workshop concentrated on the formation of the COOPEUS mission and outlining of the transatlantic landscape analysis of research infrastructures.

The second workshop was held at the American Geophysical Union's (AGU) Fall Meeting in San Francisco, CA in December 2014, where the focus of the COOPEUS roadmap workshop was on defining the potential common actions in the perspective of technological capital (including data and related RI technologies). The San Francisco workshop also included a meeting with the stakeholders to enhance the communication with the funding organizations (such as NSF and EC), and to learn more about the latest developments regarding future funding opportunities.

During the European Geoscience Union General Assembly, in Vienna, in April 2015 the COOPEUS roadmap workshop focused on identifying common interests of future collaboration in relation to human and cultural capital, and on discussing the most suitable organizational framework for future COOPEUS collaboration.

After these workshops, the WP8 writing team created the first full draft version of the COOPEUS roadmap in June 2015 (EC Deliverable D8.3). The first draft version was circulated to the COOPEUS partners for comments in June-July 2015. COOPEUS partners have further discussed the roadmap preparations and the content during the COOPEUS Final Meeting (EC-funded part of the COOPEUS), held in Brussels in 29-30 June 2015.

The next steps in the drafting process:
During the August 2015, the 2nd version of the COOPEUS roadmap will be written and this version will be submitted to the European Commission as the Deliverable D8.4. As the roadmap process is still on-going, the COOPEUS roadmap document will be distributed for wider user and stakeholder communities for additional consultation during the autumn 2015 and winter 2015/16.

While version control of this document anchors our joint roadmap in time and serves as a baseline understanding, we consider this a living document subject to future review, re-evaluation, and refinement. The latest version of the COOPEUS roadmap can be find at www.coopeus.eu.

2. EU and US research infrastructure landscape and status of collaboration

For future collaborative work, it is necessary to understand the current situation, the dynamics, and the differences and similarities among RIs in different disciplines and on different continents in the existing landscape of the research infrastructures. In this context, the landscape analysis of the research Infrastructures means a more systematic and conceptual evaluation of the existing RIs using their self-identification (if available). This self-evaluation forms a basis to understand what scientific communities they are serving (which parts of the Earth System field are covered, are there still gaps in the RI landscape), what are their main RI services and products, what is the maturity level of the RIs (construction, operations), and how sustainable the RIs are (depended on short-term/long-term funding).

The overall landscape analysis has been performed from the perspective of scientific domains/disciplines, i.e. a perspective of suppliers (research infrastructures), in contrast to the perspective of looking at the research infrastructure landscape from the service provision point of view.

This analysis is very much dependent on the definition of a Research Infrastructure. The current use of the term in Europe (and in this document) is very much in line with the ESFRI definition of an RI[1]:

> *The term 'research infrastructures' refers to **facilities, resources and related services** used by the scientific community to conduct top-level research in their respective fields, ranging from*

[1] http://ec.europa.eu/research/infrastructures/index_en.cfm?pg=what

social sciences to astronomy, genomics to nanotechnologies. Examples include singular large-scale research installations, collections, special habitats, libraries, databases, biological archives, clean rooms, integrated arrays of small research installations, high-capacity/high speed communication networks, highly distributed capacity and capability computing facilities, data infrastructure, research vessels, satellite and aircraft observation facilities, coastal observatories, telescopes, synchrotrons and accelerators, networks of computing facilities, as well as infrastructural centres of competence which provide a service for the wider research community based on an assembly of techniques and know-how.

Importantly, this definition concentrates on the facilities, infrastructures, and centres of competence, specifically not including organizations that actually perform research, which can of course be part of the RI operations, but not in direct research role. This clarification is especially important in the US analysis, due to the multitude of funding agencies and their approach to the concept of RI and lack of explicit definition of an RI at a Federal level. Many research-supporting facilities exist outside of this definition also in the EU, a factor which could be further evaluated in future iterations of the landscape analysis.

2.1. Landscape overview

The environmental RIs are often built from bottom-up needs of the scientific communities, bringing together and developing the naturally forming collaborations needed for Earth/Environmental System sciences. Therefore, the original aim, scope and the construction set-up of the environmental RIs have been initiated by different needs and have resulted in very different realizations of the RIs. This bottom-up, community-driven development pathway has created a heterogeneous landscape, with diversity of disciplines and approaches. This makes the landscape analysis and understanding the field more challenging. The heterogeneity is however also very valuable from the Earth/Environmental System understanding point-of-view, as the naturally developed viewpoints are often optimal to specific problems or processes. Earth Systems are tremendously complex system, and our ability to comprehensively understand these systems must be derived from different and complementary scientific disciplines and approaches.

Our approach to the landscape analysis of the RIs was first to evaluate the COOPEUS partner organizations, and then to extend this approach towards RIs outside of immediate COOPEUS collaboration to understand the entire environmental RI field in more detail. It should be noted that this process is iterative, and the overall landscape image will continue to be further developed during our on-going US COOPEUS program and European RI collaboration.

The landscape methodology is mostly based on publicly available information of the RIs, which is also a limitation as many of the potentially interesting RIs outside of the COOPEUS projects do not specifically mention the methodology, user groups, or in some cases even the offered products in the public websites. The difficulty of collecting information is also connected to the aforementioned diversity in the RI construction and operation. The viewpoint analysis below and the aspect analysis are mostly based on the publicly available information, with further corrections and details provided by the COOPEUS partners. For the limited work done for non-COOPEUS RIs, no direct interaction with the specified RIs was done and the results are only indicative.

2.1.1 Primary viewpoint analysis of the RIs

As mentioned earlier, the Earth System is an extremely large, complex and interconnected system, spanning tremendous temporal and spatial scales. Naturally, no single RI can cover such a span of processes, and each one of them has selected a subset of the whole Earth System for study. We use the term *viewpoint* to represent this choice of subset and origin of the RI. No RI can described by a single viewpoint, and issues such as observation scale (in spatiotemporal coverage of the observations and/or scales of processes studied) and methods are natural additional constrains of the scope of RIs. However, often a single *primary viewpoint* can be determined that is usually embedded in the mission statement or short description of the RI. Thus, our conceptual categorization is based very much on the *self-identification* of the RIs – what the RI operators present as the main defining characteristic of their RI. Put another way, we recognize that most RIs are a mix of more than one characterization listed below, which is the basis of the aspect analysis in the next section.

During our roadmap planning workshops, we acknowledged that there could be a number of ways to characterize the RI landscape, for example the degree they are organized from top-down mandates or the strength of bottom-up community engagement. We chose the conceptual framework (Figure 2) because it provides the most useful concepts to i) communicate and engage with other RIs, and ii) advance future actions and governance. Here, the RI landscape analyses were merged into the following conceptual framework with the caveat that they are not mutually exclusive of all RIs.

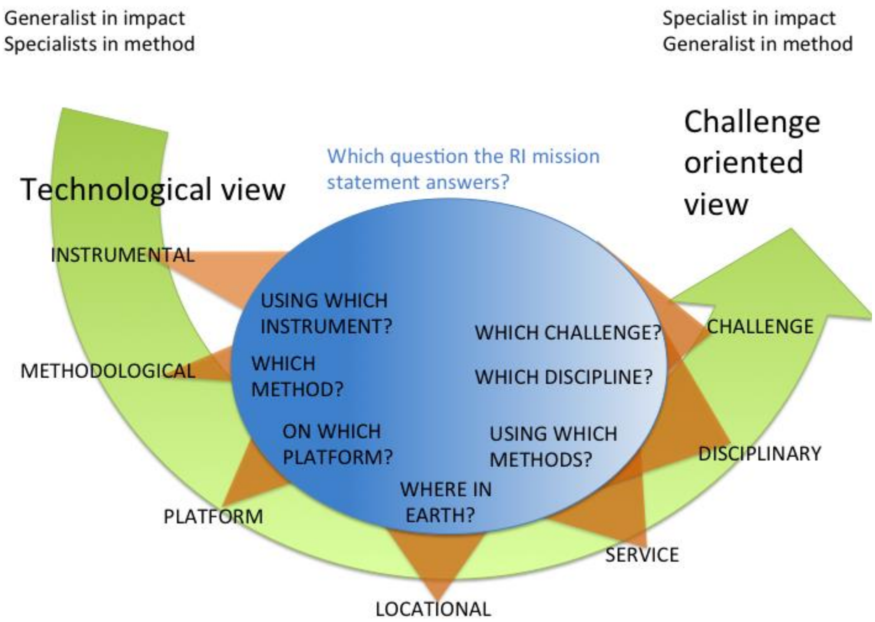


Figure 2. Simplified primary viewpoint analysis: Which question does the RI main mission question answer?

Instrumental RIs are based on a single instrument (or single type of instruments). They can be single-sited or distributed research infrastructure facilities, but the main characteristic point is the concentration on the technology of observation, instead of the subject of observation. It should be noted that the term 'instrument' can refer to hard instruments as well and other data collection approaches, as in the case of biodiversity measures. These kinds of RIs are typically very diverse in applications, but do not specialize on some specific Earth/Environmental System challenge. Example in the COOPEUS community would be EISCAT_3D, which is well defined by the small set of large instruments (multiple sending and 3 receiving radars).

Methodological RI defines itself via the overall method of RI operations, instead of specific technology or observation type. Perhaps most common in context of Virtual Laboratories or Data Centre RIs, where the methodology (e.g. Data Science services) is in the core of the RI, or RIs specializing in specific property of some Earth Systems process. Examples of such a RI in COOPEUS are LifeWatch and DataONE.

Platform-based RI is defined by the observation platform used, instead of specific instrument(s). They are close to the methodological RI definition (above), but are more concentrated on the physical infrastructure and the main services they provide (physical access and use instead of data). Typical examples are ship and aircraft based RIs. The clearest examples (outside of COOPEUS) are European EUFAR aircraft RI or EUROFLEETS2 research vessels RI.

Locational RI is defined by the research location, regardless of the observation type, methodology, Earth System challenge or even discipline of the parts of the RI. An example of such RI is SIOS (outside of COOPEUS) in Svalbard islands that attempts to capture all perspectives of Earth System science in the Arctic region. However, many of the COOPEUS partners do have some locational factors in the design as a secondary characteristic.

Service RI is defined by (single) service they provide, beyond any other factor of the RI design. Typical examples are RIs, which only provide a single aspect of the possible RI operation. Example (outside of COOPEUS) is European INTERACT, which primarily provides access services to observation sites. These RIs are very similar to Platform based RIs, with the main difference being clearly defined concentration on single service.

Disciplinary (or domain) RI self identifies as a common RI platform for studies in a whole discipline or sub-discipline of the Earth System sciences – collecting data and supporting services from wide variety of different approaches within the discipline or Earth System domain. Example of such RI is European EPOS infrastructure on the Solid Earth domain, and EMSO from the Marine domain.

Challenge-based RI (or Challenge-based) is an RI that concentrates on a specific Earth System challenge, trying to provide observations, tools and services to answer it. An example of such RI in COOPEUS is ICOS providing data, modelling and access services for GHG observations, and parts of NEON in US doing similar activities.

This list is not meant to be exhaustive, and it only describes the RIs that were analysed for this work. The selection of the conceptual framework will also affect the type of RI services they provide. The more technological the approach is (see Figure 1), the more likely it is that the RI services are applicable to many Earth System challenges partially, but less likely to answer them in whole – making the use of multiple RI data sources more important. Similarly, more problem-oriented RIs might have excellent opportunities to answer the issues related to their specialty, but the generalization of the RI services to other uses might be more challenging. These are however just general trends and should not be considered definitive aspects of individual RIs.

Additionally, many of the RIs can have other defining characteristics, either as additional viewpoints (often Earth System domain, discipline or sub-discipline definitions), primary product, or by specifically defining area of operation (spatial and/or temporal), scales of studied parameters or processes, or by specifying some subset of possible products.

It is important to acknowledge that any such categorization contains a strong subjective element, and thus this landscape analysis is a basis of a process of development and continuous updates together with the RIs.

2.1.2 Aspect analysis of the RIs

Just using the viewpoints to understand the RIs can be misleading, as many of the RIs have multitude of aspects defining their organization and products.

Different aspects of RIs can be used to evaluate their aims and focal points. It is important to understand that these axes, like the viewpoints above, are not complete descriptions of the RI operations. They are not dichotomies (as they can have a sliding scale), and often can have both aspects in differing quantities. Very large integrating RIs (e.g. EPOS or EMSO) can have multitude of sub-RIs, which could have much more concentrated aspect than the whole. It should be also noted, that these are not comprehensive definitions of the RIs, and some of the aspects have much less importance for some of them. This kind of set of parameters provide more complete idea of the RI goals and organization, but are necessarily less succinct and harder to analyse for effective actions.

The RIs in COOPEUS were also analysed based on the following aspects of their organization and nature. The list also combines typical COOPEUS challenges connected to these aspects, which can help to determine suitable actions to increase cost-effectiveness, interoperability and efficacy of the RIs.

Physical vs. Virtual
A **Physical RI** is concentrated on detecting or experimenting with the actual physical environment. They produce of then non-reproducible information on the state and processes of the Earth System.
Typical *COOPEUS challenges: data streams from instruments, metadata standardization and collection, observation standardization, technical challenges*.
Virtual RI is concentrated on analysis, combination and simulation, using existing observations as a basis of their operations.
Typical *COOPEUS challenges: Handling large datasets, user access, metadata standardization, standardized documentation, workflow documentation.*
Often RIs have both physical and virtual aspects, although purely virtual RIs are getting more commonplace (e.g. data integration based RIs).

Observations vs. Experiments
Observations mean in this context passive collection of findings, from nature or e.g. from existing data collections. Important part is that the main task is collecting information that already exists, or is available to collect with minimal change in the RI procedures. Key point of observations is the limited amount of direct user input on the specific product used. Often observational RIs can be considered to be "data oriented", i.e. they provide the data as-is, however this term can be misleading, as many of the data concentrated RIs are actually providing analysis opportunities.
Typical *COOPEUS challenges: Long-term secure storage, data provenance, standardized documentation, Dynamic data citation*
Experiments refer to specific, well characterized and designed user driven experiments, where the main aspect is manipulation or simulation of nature. The main differentiating factor from observational is the active role of the user in manipulation of the nature or the facilities RI provides. Examples are e.g. simulations, or ecosystem manipulation experiments. These kinds of RIs can sometimes be referred as "access oriented" RIs.
Typical *COOPEUS challenges: Workflow documentation, common access policies*

An RI can have both experimental and observational aspects, depending on the user needs.

Single site vs. **Distributed**
Single site in this context refers to a site with centralized single location. In physical RIs, this usually refers to single physical location, or cluster of sites in close proximity to each other. In virtual or data oriented RIs this refers to a single location or institute for data infrastructure.
Typical COOPEUS challenges: Secure data storage, Data provenance, common access policies, data documentation (representability aspect).
Distributed RIs consist of multitude of relatively similar scale facilities, located in wide geographical area.
Typical COOPEUS challenges: Dynamic data citation, heterogeneous datasets, data quality control.
An RI can have both single location and distributed aspects, e.g. by having a concentrated data centre in one location, but having a widely distributed observational facilities.

Sustainable or project based
Fully **sustainable RIs** have a long-term (more than 10 years) sustainable funding scheme, and are considered to be very stable in the long-term. This kind of funding can be either institutional or user fee

based, with the main consideration being the perceived longevity. This can be also demonstrated by e.g. long history of operations, or wide and demonstrated user base.
Typical *COOPEUS challenges: Locating new user groups, re-structuring of data services for new downstream users*
Project based RIs are typically more fluid in their long-term plans, as they are dependent on competition based funding schemes. This could be also used as indicator of not yet demonstrated user fee sustainability, or uncertainty in the funding commitments from the funding agencies.
Typical *COOPEUS challenges: Interaction with existing RIs, finding sustainability via interoperability, new user groups, long-term security of results.*
Factoring this aspect of the RI can sometimes be very difficult and sensitive issue. In addition, a RI can have parts that are very sustained, and parts which are based on more competed funding sources.

Fixed vs. Moving
Fixed installations in physical RIs refer to observation or experiment sites, which are fixed in location. This could refer to observation stations, undersea cable systems, or radar installations. For virtual RIs, a fixed aspect points to fixed physical data infrastructure (e.g. servers owned by the RI)
Typical *COOPEUS challenges: data documentation (representability aspect), standardization of observations, standardization of metadata.*
Moving installations in physical RIs refer to mobile platforms for the observations or experiments, such as ships, airplanes or freely floating buoys. Moving installations in virtual RIs refer to highly virtualized IT infrastructures, where the actual location of the services and data are not fixed (e.g. rented server space).
Typical *COOPEUS challenges: data security, dynamic data citation, synchronicity, reproducibility of analyzes.*
RI can have both features present, especially in different parts of the RI (e.g. fixed installations for observations, but additional moving observation facilities, or virtualized data storage).

Continuous vs. intermittent
Continuous RIs are operating operationally without interference from the user groups. Typical examples are continuous observing networks, or data centres providing data services to users.
Typical *COOPEUS challenges: big data storage, sustainability, data provenance, usability for user groups, standardization of observation systems.*
RIs working on more **intermittent** basis are operating on specific periods, often defined by user requirements (e.g. aircraft observation period) or physical phenomena (e.g. solar storm). Many of the simulation RI products are more intermittent in nature (i.e. they require user request).
Typical *COOPEUS challenges: data documentation (representability aspect), common access policies, common research strategies, optimizing the data storage capacity (what specific data to store for future research)*
Parts of RI can have different operation strategy.

Open service vs. controlled service
Open service RIs have their products openly available for all user groups. In the most open case, the access is anonymous, but many other models of access are possible.
Typical *COOPEUS challenges: data provenance, security issues, sustainability of products, standardized usage metrics.*
Controlled service requires pre-approval from the RI. This type of access is typical for RIs providing sensitive data, experiments or physical access.
Typical *COOPEUS challenges: access standardization, sustainability, finding new user groups.*
Parts of RI can have different control level.

Generalist vs. Specialist
Generalist RI provides data or services for wide variety of uses, but does not concentrate on solving specific scientific problem. Typical examples of such RIs are many of the data integration RIs, or instrumental RIs (e.g. accelerators).

Typical *COOPEUS challenges: Sustainability (which problems does RI solve?), data provenance (usability for use), standardized usage metrics.*
Specialist RI concentrates on a specific scientific, environmental or societal challenge, and provides results for solving this specific issue.
Typical *COOPEUS challenges: generalization of results, finding new user groups*
Often RIs have both aspects somehow present, but dominance of one is also quite typical.

Operational vs. in construction
Operational RIs are already operating in full capacity, with well-defined user groups, products and interfaces. Such RIs are often also sustainable. However, changing operation standard can be challenging. Note the high similarity to sustainable aspect above, although there are clear conceptual differences (operational RI can be also project based, and RI in construction can be fully sustainable with long-term funding).
Typical *COOPEUS challenges: Locating new user groups, re-structuring of data services for new downstream users*
RIs **in construction** have still many developmental issues unsolved, such as physical or virtual RI construction, development of policies, connections to user groups etc.
Typical *COOPEUS challenges: [depending on the construction level]*
Naturally, an RI can have parts that are fully operational, with construction and development of other factors of the RI.

Single discipline vs. multidisciplinary
Disciplinary RI is concentrated to serve a single well-characterized user group, such as particle physicists, ecosystem biodiversity researchers or meteorological services.
Typical *COOPEUS challenges: finding new user groups, generalizability, which challenges can solve?*
Multidisciplinary RI provides services for wide variety of sciences, with no specific main user discipline.
Typical *COOPEUS challenges: Data documentation, data heterogeneity, terminology issues.*
An RI can have parts that are more discipline-oriented and parts that have high interdisciplinary nature.

2.2 Analysis of the COOPEUS RIs

ICOS
Primary viewpoint: Challenge based, carbon dioxide and greenhouse gasses.

Aspects: Majority **physical** RI (observation network), some virtual parts (Carbon Portal, CO_2 emission simulation). **Observational**, minor experimental part (simulation). **Distributed**, both in physical and virtual infrastructure. Majority **fixed installations** (also in data centres), but possible future minor moving installations (ships). Majority **continuous observations**. **Open service**. **Specialist RI** on CO2 observations and climate change. Mostly **operational**, with minor parts still in construction (data facilities). **Disciplinary** in the sense of concentrating on CO2 observations, however some multidisciplinary parts (ecosystems, atmospheric transport).

NEON
Primary viewpoint: Challenge based, on one side carbon dioxide, greenhouse gasses, on another biodiversity.

Aspects: Majority **physical** RI (observation network). **Observational**, minor experimental part (access to sites). **Distributed**, both in physical and virtual infrastructure. Majority **fixed installations** (including data centre), but possible future minor moving installations (airplanes). Majority **continuous observations**. **Open service**, some access-related closed service aspects. **Specialist RI** on CO2 observations and climate change.

Mostly **operational**, with minor parts still in construction. **Disciplinary** in the sense of concentrating on CO2 observations, however some multidisciplinary parts (ecosystems).

EISCAT-3D
Primary viewpoint: Instrumental, radar facility

Majority **physical** RI (radar). **Observational**, but due to the intermittent design has some experimental features. **Single-site**, in physical, distributed aspects in the virtual infrastructure. Majority **fixed installation**, but possible future minor moving installations (airplanes). Majority **intermittent observations**. Data is **open access**, but control on the experiments in controlled. **Generalist** as the radar results can be used for multiple purposes. Mostly **operational**, with minor parts still in construction. **Disciplinary** in the sense of technology, but can be considered to have multidisciplinary features, especially in developing parts of the RI.

AMISR
(Text to de written, similar to EISCAT_3D)
Primary viewpoint: Instrumental, radar facility

EMSO
Primary viewpoint: Disciplinary or **domain RI**, seafloor and water column.

Majority **physical** RI. **Observational**, but has some experimental features. **Distributed**, in physical, single-site aspects in the virtual infrastructure. Majority **fixed installation.** Majority **continuous observations**. Data is mostly **open access**, but control of the experiments in controlled and some data is not available. **Generalist** as the EMSO results can be used for multiple purposes. Mostly **operational**, with minor parts still in construction. **Multidisciplinary** in the sense of wide range of studies done, but can be considered to have disciplinary features, especially if one considers marine sciences as a defining feature.

OOI
(Text to de written, similar to EMSO)

EPOS
Primary viewpoint: Disciplinary or **domain RI**, solid earth sciences.

Majority **physical** RI. **Observational**, but with parts with experimental features. **Distributed**, in physical, single-site aspects in the virtual infrastructure. Majority **fixed installation.** Majority **continuous observations**. Data is mostly **open access**, but control of the experiments in controlled and some data is not available. **Generalist** as the EPOS results can be used for multiple purposes. Mostly **operational**, with minor parts still in construction. **Multidisciplinary** in the sense of wide range of studies done, but can be considered to have disciplinary features, especially if one considers solid earth sciences as a defining feature.

EARTHSCOPE
Primary viewpoint: Disciplinary or **domain RI**, solid earth sciences.

Majority **physical** RI, but with strong virtual aspect (especially as the EARTHSCOPE central facility). **Observational**, but with experimental features present in the virtual part. **Distributed**, in physical, single-site aspects in the virtual infrastructure. Majority **fixed installation.** Majority **continuous observations**. Data is mostly **open access**, but control of the experiments in controlled and some data is not available. **Generalist** as the EARTHSCOPE results can be used for multiple purposes. Mostly **operational**, with minor parts still in construction. **Multidisciplinary** in the sense of wide range of studies done, but can be considered to have disciplinary features, especially if one considers solid earth sciences as a defining feature.

DataONE

Primary viewpoint: Methodological, data repository and collection.

Majority **virtual** RI. **Experimental** RI combining external data sources into a virtual laboratory and access. **Distributed** in the virtual infrastructure. Majority **fixed installation** in virtual RI**.** Majority **intermittent** experiments, driven by the user base. Data is mostly **open access**, but control of the experiments in controlled. **Generalist** as the DataONE results can be used for multiple purposes. Mostly **in constructions**, with significant parts operational. **Multidisciplinary** in the sense wide selection of properties available in Earth Sciences.

LifeWatch

Primary viewpoint: Methodological, data access and virtual laboratory.

Majority **virtual** RI. **Experimental** RI combining external data sources into a virtual laboratory. **Distributed** in the virtual infrastructure. Majority **fixed installation** in virtual RI**.** Majority **intermittent** experiments, driven by the user base. Data is mostly **open access**, but control of the experiments in controlled. **Generalist** as the LifeWatch results can be used for multiple purposes. Mostly **in construction**, with minor parts operational. **Disciplinary** in the sense of biodiversity studies.

Table 2. First estimates of the approximate aspect analysis of COOPEUS partners. * = Strongly present, ** = present, * = weakly present, - = not present**

Aspects	ICOS	NEON	EISCAT-3D	AMISR	EMSO	OOI	EPOS	EARTHSCOPE	DataONE	LifeWatch
Physical	***	***	***	***	***	***	***	***	-	-
Virtual	**	**	*	*	**	**	**	**	***	***
Observations	***	***	**	**	***	***	***	***	-	-
Experiments	*	*	***	***	*	*	**	*	***	***
Single-site	-	-	***	***	-	-	-	-	-	-
Distributed	***	***	-	-	***	***	***	***	***	***
Fixed	***	***	***	***	***	***	***	***	***	***
Moving	*	*	-	-	*	*	-	*	*	*
Continuous	***	***	*	*	***	***	***	***	-	-
Intermittent	*	*	***	***	*	*	**	*	***	***
Open service	***	***	**	***	***	***	***	***	***	***
Controlled service	*	-	***	-	*	*	**	*	-	-

Generalist	*	*	***	***	**	**	***	***	***	***
Specialist	***	***	*	*	**	**	*	*	-	-
Operational	**	**	***	***	***	***	***	***	**	*
in construction	*	*	*	*	*	*	*	*	**	***
Single discipline	***	***	*	*	**	**	***	**	*	***
Multidisciplinary	*	*	***	***	***	***	**	***	***	*
				????		????		???		

2.3 RI landscapes

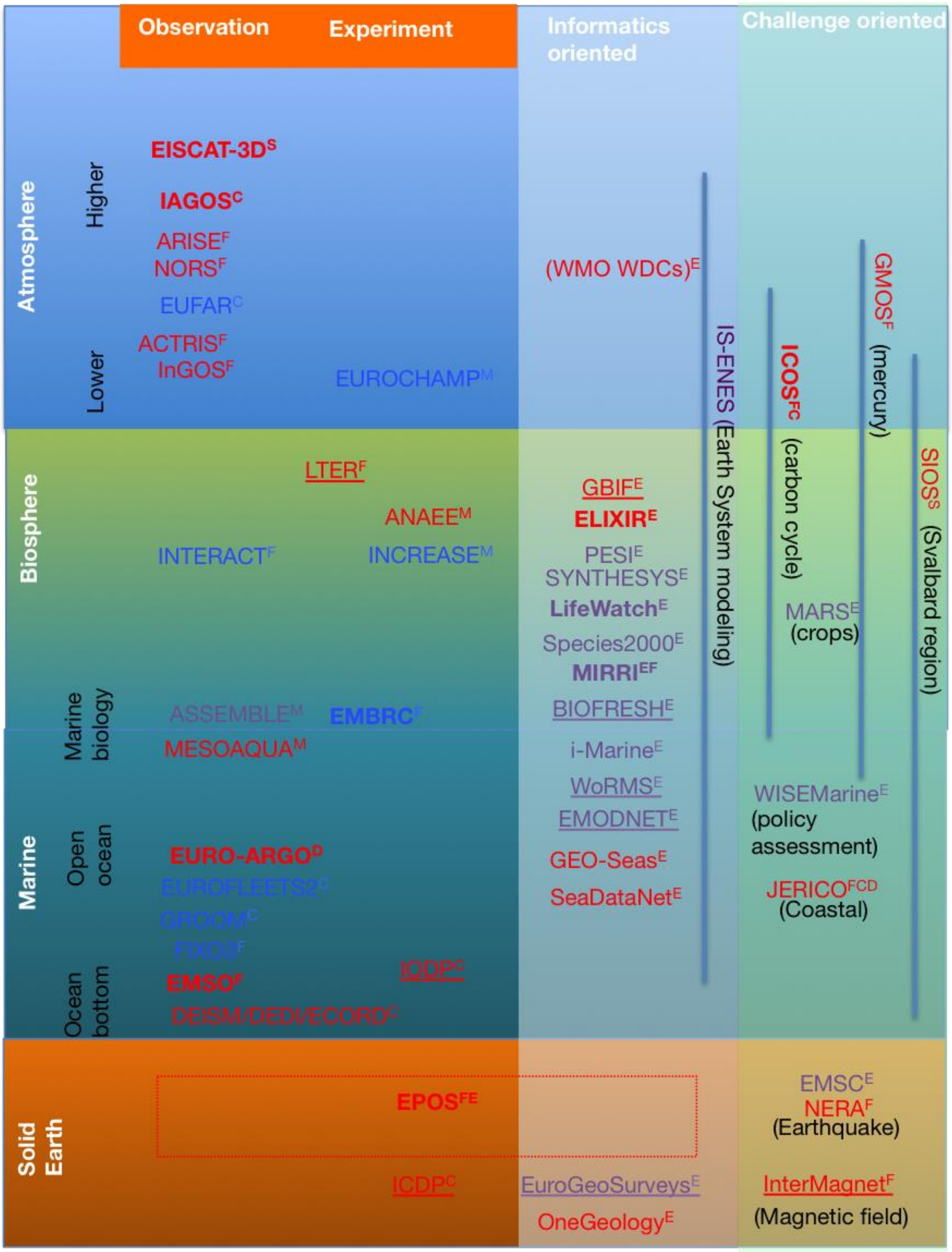
While we recognize this importance of analysing COOPEUS partners to solidify future planning, at the same time, we also recognize that COOPEUS activities must partner with a broader suite of related international/transatlantic research infrastructures. Addition of these other RIs was preformed through website information, direct communications, and other sources (e.g. ESFRI reports).

EU landscape of the RIs is very much defined by ESFRI roadmap and associated processes from the European Commission. These actions make some issues related to the landscape analysis easier: There is a common European context (at least for recent RI developments) and the RIs from different disciplines have common organizational levels.

Even on the EU side, the complexity of the RI viewpoints and RI aspects makes it hard to present the overall landscape using any of the potential mapping parameters. One example of the RI landscape is represented in Figure 3. In Figure 3, a hybrid approach is used, where the domain information and (in some domains) vertical spatial extent is presented in the vertical axis, the horizontal axis instead represents the methodological category of each RI. This is naturally a simplified figure (e.g. almost all RIs have an informatics relevant data-centre or data service), but can be used as an initial view of the overall RI landscape in Europe. A lot of additional information (e.g. organizational status, primary observation type) is given in colours and superscripts.

On the US side, the word “research infrastructure” is more generally and has different definitions for their respective agencies, sponsors and organisations. In addition, many of the observatory/research infrastructure-type organisations can be single (member) State-owned as in the EU, or supported by a single Federal agency, or some combination thereof as in the US. This sometimes results in a mis-match of funding approaches. Here, we focus this landscape analyses on the scientific capabilities, rather that the programmatic structures that enable them. Moreover, in Europe the focus has been in the pan-European level research infrastructure, we also decided to concentrate in the US side on the Federal level organisations and service providers. In Europe, also the strategic decision on pan-European level RI activities in centralised to the ESFRI and in addition to the EU Member State funding, EC is also providing coordination support for European level RIs. Therefore, also the RI funding policy landscape is coordinated, as in US the multitude of Federal agencies and funding bodies involved in the RI operations make the identification of US RIs even harder. Figure 4 attempts to capture some of the key environmental RIs on the US side, even though without the additional organizational information presented in the European map.

Overall, the landscape analysis presents the first comprehensive attempt to understand the whole RI field in systematic way. This work is intended as a starting point to support the roadmap process, and will be further developed to better understand (especially) the US RIs.



	Distributed fixed site	Distributed moving site	Controlled moving	Single site or region	Mesocosm	E-infrastructure
Example	Observatory network	Ocean floater	Airplane	Radar receiver	Reaction chamber	Data center
Symbol	F	D	C	S	M	E

RI organization status	Primary product
Other or unclear	Observation data
I3 Project or similar	Research Access
ERIC or other legal entity	Integrated data products/ Data analysis

Figure 3. Example of potential landscape figure for the European RIs.

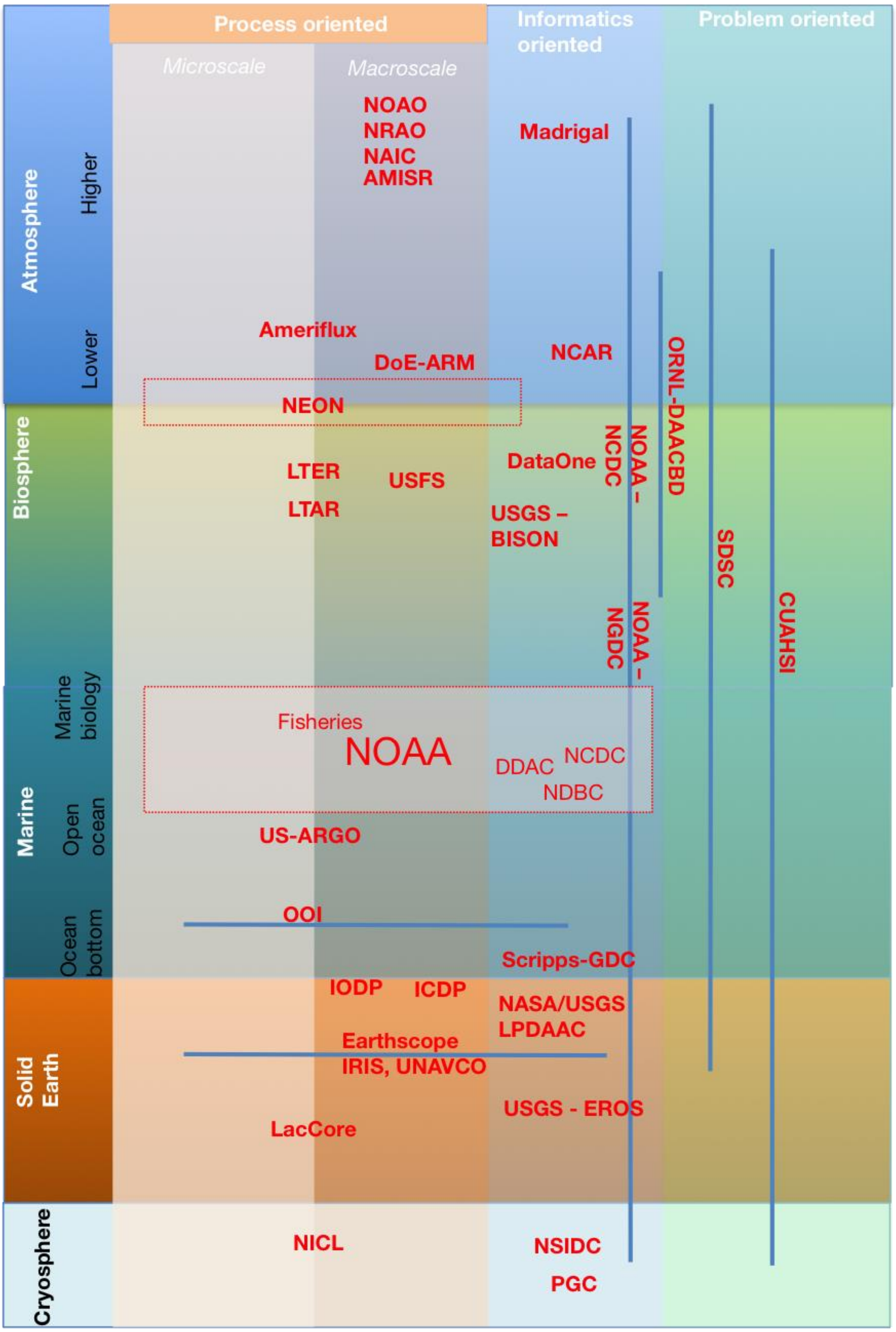


Figure 4. Example of potential landscape figure for the US RIs.

3. COOPEUS Mission statement

For community-driven activities, such as in the case of COOPEUS, it is important to jointly discuss, define and agree on the common future aims and scope of the activities. The COOPEUS partners are willing to continue an effort to link data of the research infrastructures across the Atlantic. The COOPEUS partners have selected to follow a federated approach on data cooperation, meaning that the execution and implementation of the COOPEUS outcomes is voluntary based on the capability and available resources of each individual RI, i.e., it is not meant to be prescriptive. COOPEUS aims to produce a global impact by building an active community around the involved environmental thematic networks and to create a common, long-term platform for collaboration.

COOPEUS mission statement

COOPEUS facilitate the global accessibility of data from research infrastructures to advance our understanding across Earth systems through an international RI community driven effort, by:

- Removing technical, scientific, cultural and geopolitical barriers for data use;
- Promoting the flow, quality and preservation of information;
- Engaging user communities; and
- Accompanying societal and scientific needs.

The purpose is to facilitate the evolution of international research infrastructures to advance our understanding of Earth systems through four strategic goals:

Strategic Goal 1: Removing technical, scientific, cultural and geopolitical barriers for data use, e.g.,

- Develop support mechanisms to assure data sovereignty
- Promote free, open, timely access of data and the associated data policies
- Harmonize the protocols, algorithms, standards and best community practices
- Facilitate state-of-the-art data access methodologies (e.g., brokering) and development of novel data discovery tools

Strategic Goal 2: Coordinating the flow, integrity and preservation of information (among e-infrastructures), e.g.,

- Develop and promote the use of persistent Identifiers
- Develop and promote the use of metadata and data format standards
- Develop and promote the use of ontologies, semantics, and controlled vocabularies
- Quality = data integrity?, or Quality = QA/QC, traceability, metrology
- Develop, promote sound, and execute defensible Data Management plans and archival guidelines

Strategic Goal 3: Engaging and enabling both bottom-up (user) and top-down (directives) communities, e.g.,

- Managing a governance structure to can foster broad, bottom-up, open-engagement of all organizations interested in advancing our mission statement.
- Developing the virtual organizational structure and fostering the culture for re-use, re-purposing and the sustainment of the collective harmonization of data
- Optimizing data resources (avoiding functional and organizational redundancies)
- Comprehensive support for community engagement

Strategic Goal 4: Contribute to address evolving societal and scientific needs by providing information on Earth System, e.g.,

- Identifying and being responsive to current and new scientific frontiers and decision-making needs

4. Roadmap – implementing the COOPEUS mission

As challenges to foster interoperability among different information and knowledge systems are not limited to the data itself, but also activities such as education and training, trust and community building (changing culture) are equally relevant for achieving the set COOPEUS strategic goals. Therefore, we have conceptualized needed actions in following themes: data and technological capital, human capital, cultural capital, organisational framework and outreach. Our ability to address each of our strategic goals relies on integrating the respective technical, cultural and human needs and resources.

The framework of this Roadmap follows the logic outlined in the COOPEUS Mission Statement. For each Strategic Goal, we include a rationale ***'preamble'*** and findings as part of a ***'findings'***. We then identify actions that must be taken to advance our Mission Statement (re. Interoperability) and noted as ***'imperatives'***. These imperatives are meant to identify more immediate short-term actions. Lastly, we identify ***'frontiers'*** that represent needed activities on longer time horizons.

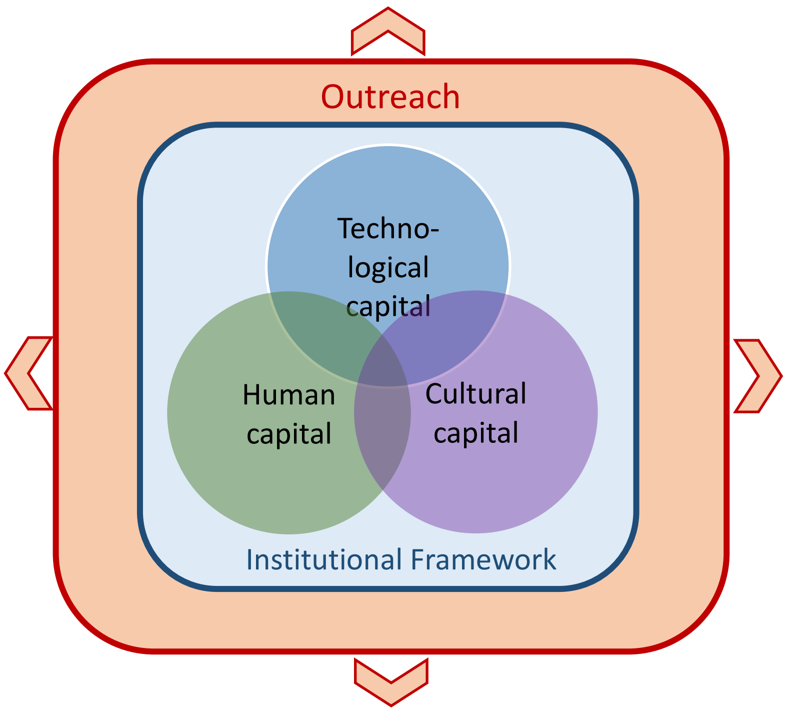


Figure 5. The components of the COOPEUS roadmap that needs to tackle to achieve the COOPEUS mission and strategic goals.

4.1 Strategic Goal 1: Removing technical, scientific, cultural and geopolitical barriers for data use

***Preamble*.** The COOPEUS mission statement identifies many data-, technical, scientific, cultural-oriented issues that the COOPEUS community sees as important steps towards enhancing the data interoperability among the international environmental data providers. The topics are related to removing all barriers for data use and promoting technology science, and culture for the flow, integrity, access and preservation of information. The COOPEUS community identified both common actions and science field specific actions for future collaboration. Not all these Imperatives and Frontiers are meant to be prescriptive, rather developed by a community driven approach.

Finding 1*: *Common description of data systems

A key challenge is how to make interoperable the environmental and earth science data, whose very nature is extremely heterogeneous in nature, as well as the needs to acquire, store, curate and disseminate these data (technical capital). Different user communities and science (sub)discipline have different needs to manage these data as illustrated by the landscape analysis. To achieve interoperability the needs of the collective user community and collective data management systems have to be identified, mapped, and broadly communicated. This finding includes the need for broader engagement of data scientists, computer scientists working other with earth system scientists (technical, cultural and human capital).

Imperative: to increase our knowledge of all the partners and related data providers' data management systems (including descriptions of data levels, identification of the subsystems in the management structure). This would enable and to understanding each other's technical requirements and e-infrastructure set-ups, where there are commonalities to build upon, and where there are knowledge/functional gaps that have to be addressed jointly. Hence, an imperative is to perform a common analysis of the COOPEUS partners' data management systems for better understanding of the similarities and the differences in the data architecture. The analysis could build upon the ENVRI reference model framework as a conceptual tool for describing the RI data management systems in a common manner. Addressing this imperative would develop the basis for future engagement with the joint data management and user communities. Key to achieving this imperative is fostering collaborative cultures.

Frontier: to better understand the needs and develop (accordingly) the different data quality indicators (data processing steps and data level definitions) and on service provision of high-level data products needed by the research infrastructures.

Finding 2: Collaborative advancement on Standards and Metrology

Understanding *how we know*, *what we know* is a classical epistemological question, which is a primary scientific tenant in our ability to utilize data from one source with another. Interpretation and synthesis of data from different sources is dependent on its signal-to-noise ratio and its inherent uncertainties, particularly if we are to use these data in any Bayesian framework, i.e., data uncertainties have to be known *a priori* to be used in state-or-the-art data assimilation approaches. We also fully expect large-scale data will be used in the future in ways we cannot fully anticipate today. Hence, all data should be able to trace to either; known and recognized international standards, first principles, or best community practices.

Imperative: To develop a community driven forum, and in partnership with standards holding bodies, to i) identify the needs of respective communities to develop standards and a metrological defensible approach for their data; ii) assist in implementing these standards at the level of an organization; and iii) develop tools to assist in building uncertainty budgets for data products that at defensible by stand holding body, i.e., Guide to the expression of uncertainty in measurement (GUM), Joint Committee for Guidelines on Metrology (JCGM), 100:2008.

Frontier: Jointly develop the international discourse and forum to advance these Findings.

Finding 3: **Supporting the common data licenses following Creative Commons standards**

Among the environmental research infrastructures the data policies in respect to open access varies, as there are discipline-specific requirements and traditions to approach this matter. In addition, many COOPEUS partners are using heterogeneous data licensing procedures in relation to data access. To create a user-friendly licensing environment and to foster broad usage of harmonized data, our finding aims to collaborate on data licensing so that all users are able to easily navigate through the data license environment and are able to cross-link and reuse the data but still attribute the data providers and state the limited liabilities of the research infrastructures in a correct manner when re-/cross-using of various data sets. Machine readability of licenses is a necessary development. In the COOPEUS community, examples and expertise that can be utilise in the data licenses harmonisation exits, e.g. the use of standard Creative Commons licensing approaches by all FDSN networks (International Federation of Digital Seismograph Networks).

Imperative: A COOPEUS action for comparing currently used licenses and support of the commonly acceptable Creative Common standard for research infrastructures is suggested for the future collaboration. To seek endorsement of and promote the use Creative Commons licensing techniques within COOPEUS RI partners (Carbon, Oceans, seismic networks).

Frontier: Jointly develop the international discourse and forum to advance these ***Findings***.

Finding 4: **Long-term preservation and certification of Research Infrastructure Data Centers**

One way of removing barriers from the data usage is to increase the trustworthiness of the data by establishing the procedures for - and quality assessments of how data are archived, stored, long-term preservation, and disseminated to the user communities. This would include mapping of the RIs plans for long-term preservation and certification of the data centres of the research infrastructures. Currently, there are international efforts and initiatives for certificating data centres, such as an effort of ICSU – World Data Systems that run standardized data centre certification procedures. COOPEUS partners with data centres are encouraged to join in the certification processes while reaching the required maturity of their actions. The certification process would also promote the development of standard procedures for data centres' capabilities and capacities to manage data. This action would also enhance the relationships with external data providers and other similar initiatives.

***Imperative (all*)**:** Mapping the COOPEUS partner RIs' plans on the long-term preservation and seeking optimised international solutions for Earth system science data for long-term preservation.

Imperative (Solid Earth): Implementation of Geodetic Seamless Archive Centers (GSAC) software system (or API) by EPOS. This imperative involves the development and implementation of the seamless discovery and access to Global Navigation Satellite System (GNSS) data and derived data products such as position time series, crustal motions, and strain rate. The current state is that of some 3,000 GNSS stations in 25 countries in Europe data from only about 10% are openly shared. Data services enabled with GSAC services and the related new "Dataworks" GNSS data management open source software provides RIs a convenient and efficient system for managing their harmonized data systems with built-in capability to share with others. GSAC also aides in mirroring their data. Individual GSACs can be federated to aid activities such as EPOS that seek to provide unified federated services. After 1-y of COOPEUS/UNAVCO effort prototype installations were established at 7 European institutions in Iceland, France, Belgium (Europe wide EUREF collection), Italy, Portugal, and Greece. Based upon this experience, once the software architecture is accepted it would take perhaps 3 years to fully implement at the remaining EPOS institutions (~25).

Imperative (Solid Earth): Support the full implementation of GSAC to the remaining EPOS institutions, and advance the use and future development through technical workshops such as the 2014 GSAC workshop in Portugal, and community forums. With such workshops, forums, and a growing GSAC user community, established centres can, in turn, assist help other organizations to establish their own GSAC archives (building joint capacity).

Frontier: Certify all COOPEUS data centres as WDS certified data centres (and in the case of renew the certification of the IRIS DMC). This would build a global level of trustworthiness for users of a certified data centre.

4.2. Strategic Goal 2: Coordinating the flow, integrity and preservation of information

Preamble: The COOPEUS mission statement with the Strategic Goals identifies many issues on how to ease the scientific work by providing enhanced flow, integrity, access and preservation of scientific data. COOPEUS has defined topics such as the use of persistent Identifiers; metadata and data format standards; ontologies, semantics, and controlled vocabularies; data quality; and use of data management plans and archival guidelines to be necessary for enhancing the culture for the flow, integrity, access and preservation of information.

Finding 5: Advance the use of standard methodologies for use of Persistent Identifiers

In the Solid Earth, Carbon, Oceans and Biodiversity communities have collectively advocated the use of Persistent Object Identifiers (POIs), re. Digital Object Identifiers (DOIs). Having such capability to digitally identify data provides the context to cite data, as well as, search, link to publications, fosters reproducibility, and a myriad of recognized benefits. There are a few community-accepted protocols for POIs whose data are well described (accepted ontologies and semantics) and with fixed time and scale dimensions. However, much of environmental data are on-going time series which presents new challenges, e.g., is there a new POI for each downloaded dataset; how to reproduce specific cost of dynamic POIs; and version control to name a few. This is an active area of discourse, research, and development within several domestic community forums. Therefore, it is relevant that COOPEUS partners collaborate on the use of the standard methodologies for PIDs and promote proper attribution of the data providers within their own science communities. COOPEUS brings the international program development for POIs to bear.

Imperative: This should be done in conjunction with larger interdisciplinary COOPEUS activity on data citation methodology, and broad engagement of other (domestic) organizations, e.g., ESIP, RDA, Belmont, Forum, ENVRI^{plus}, etc.

Frontier: Jointly develop the international discourse and forum to advance these ***Findings***.

Finding 6: Creating interoperable Quality Assurance and Quality control (QA/QC) Methodologies

The methodologies are fairly well established, but developing and managing joint QA/QC plans is nascent. Statistical approaches to determine QA/QC and associated uncertainty budgets themselves, should also adopt international standards. This finding is relevant for all COOPEUS RI partners. A cultural change is likely needed to advance joint QA management programs to be successful. Epistemological approaches are rarely taught or enforced in the environmental sciences. Broad adoption and acknowledgement of the need for joint QA approaches need to permeate throughout the respective communities. This will take time, but can be fostered through community forums, discussions, training programs, metadata fields, data portals, and prototype efforts.

Imperative (all): to identify the needed QA/QC approaches to manage joint uncertainties in data across the respective science fields, and develop and implement joint QA/QC plans. These will likely include, planning meetings to identify what QA/QC efforts are made to date, identifying what is missing and how to optimize and harmonize efforts across environmental infrastructures. Joint QA/QC plans that span Research Infrastructures and joint management of these plans are needed and would be novel, effective and tangible approach. By establishing a collaborative knowledge exchange, QA document sharing, modifying the QA workflows in a similar way, and supporting common work among COOPEUS partners, COOPEUS is enabling wider adoption of standardized data QA methodologies. This will benefit the multidisciplinary users of the environmental data.

Imperative (Solid Earth): While this is limited to solid earth and specifically seismological data types, IRIS and COOPEUS partners will foster coordination of QA efforts within the FDSN (International Federation of Digital Seismograph Networks) in order to harmonize the approach to QA metrics across the FDSN members. Users of seismological data adhering to the FDSN QA standards will be able to easily assess the suitability of specific data to their specific problems. The establishment of standards and methodologies means of evaluating the quality of seismological data.

Frontier: RIS will introduce this concept at the FDSN meetings in 2015 in Prague (IUGG meeting). It will likely take a year or more or so to develop a forum, reach consensus and identify standard approaches based upon past experiences.

Frontier: Respective COOPEUS RIs (Carbon, Oceans, Solid Earth, Seismology, Biodiversity, Space Weather) to foster this discourse in respective international forums, and search resources to advance this Imperative, e.g., IRIS to introduce this concept at the FDSN meetings in 2015 in Prague (IUGG meeting). It will likely take a year or more or so to develop a forum, reach consensus and identify standard approaches based upon past experiences.

Finding 7: Develop, promote sound, and execute defensible Data Management plans and archival guidelines

(text to be written)

4.3 Strategic Goal 3: Engaging and enabling both bottom-up (user) and top-down (directives) communities – Human, cultural and institutional frameworks

4.3.1 Transferring information to knowledge – Human capital

Preamble: Human capital for COOPEUS are all the current and future trusted partners that build this actual and virtual community. It is intrinsically linked to the technical and cultural capital, but also has both tangible and intangible attributes. Intangible attributes are i) ***how we as a community transferring the harmonized data and information into knowledge***, and ii) ***how we build and grow a trusted international partners***. Tangible attributes primarily surround education actions to build the skills and expertise of using and cross-linking multidisciplinary environmental data. The paradigm shift from discipline-oriented research towards multidisciplinary open science (Science 2.0) requires new skills both from the data providers and from the users. COOPEUS partners have already organised several transatlantic workshops on capacity building, data providers' training (e.g. COOPEUS GEO and GEOSS training) and training of new users e.g. via ICOS/NEON collaboration (early career scientist and co-board of scientists to bring RIs together), EarthCube and DataONE multidisciplinary educations schemes, just to mention few. There is also an interest and willingness to continue these transatlantic education activities in the future.

Finding 8: training of Research Infrastructure users

COOPEUS partners, being prominent actors in environmental data provision, can train and facilitate the curriculum development of different type of scientists, such as data scientists and Earth system scientists. The education actions are also elemental part of the user-community engagement activities as the RI organised conferences, training and workshops provide a path to increase collaboration and common interest among users. For example, carbon data users' workshops have also shown that RIs should concentrate on the training of new users on open data and work towards interoperability. In addition, via fruitful user dialog RIs can find out which direction the cutting-edge science is developing, and what will be the future RI service requirements from the users.

Imperative: Enhance the collaboration among the COOPEUS RIs on the user training by sharing best practises on organising training events and teaching methods. In addition, COOPEUS partners can jointly organise users' training courses (both virtual and physical courses) across the disciplines.

Finding 9: Training of staff and staff exchange

A key issue for human capital development is to maintain and attract necessary expertise for the RI operations. Important part of the COOPEUS activities in this field is to coordinate the staff performance indices, qualification certification and career advancement to make sure that RI operations stay competitive for needed experts. This collaboration would then ensure that RI operators would also gain transferable set of qualifications, which could be used within the COOPEUS RI landscape and would be accepted outside of it.

Imperative: Research infrastructures can also support the staff mobility and building-up new career pathways via staff exchange programs and targeted cross-RI staff training courses (e.g. physical and online courses, webinars). Several topics related to data management, QA protocols, technical data acquisition set-ups, management of RI could be successfully shared via collaborative educational activities.

Finding 10: Citizen Science

The data provision by participative science or citizen science is one novel aspect that RIs need to take into account while developing their data management systems. This provides new opportunities for public engagement and education. However, Citizen Science also has the opportunity to contribute towards the science itself. Citizen science also requires new type of communication and engagement efforts.

Imperative: COOPEUS can provide a platform where the different experiences and knowledge can be shared among RIs. It should also be remembered that knowledge transfer from more mature RIs to starting RI communities is very valuable support. Common policies and interfaces towards citizen science are also crucial to ensure participation, usability and credibility of the methods and to provide necessary ethical background for the citizen participation (including e.g. personal information, data usage and liability issues).

Frontier activities should estimate the signal-to-noise ratio for the observed Citizen Science data. Doing this provides a mechanism to link Citizen Science data with RI data that can enhance its scientific utility. Moreover, once the signal-to-noise is estimated, efforts can be made to manage it consistently.

4.3.2 Community building – cultural capital

Preamble: Cultural capital determines and disseminates the shared goals and common vision for the multidisciplinary data integration. It is about changing discipline cultures and working towards community building, which generates trust, sharing and providing data and constructing bridges between experts in different fields. Multidisciplinary community building is a long-term effort as cultures, languages and approaches among different domains can be quite different. Developing the culture of data sharing is a long-term goal and the activities to foster a change in the cultural paradigm are many-fold. The efforts to bridge cross-cultural capabilities for data sharing will also allow us to ask questions that span disciplines that have not been yet achieved, and can enhance societal benefit.

Finding 11: Communication strategy

A key element of community building is to build a functioning communication strategy, both for internal and external communication. A successful communication strategy requires engaging of the user communities (as a bottom-up process) and a common vision on future aims and on the principles of the data service and integration. It should be also understood that sometimes the data providers are also the heavy users of the RI services and therefore the community building should take into account both perspectives simultaneously. Engagement of the users on the changing culture demands community building by convincing scientists that are trusted.

Imperative: Novel, easy and quick access to the new integrative tools is also vital, which implies that IT community should be involved in the development of new set of tools, however, the IT experts should carefully listen and respect the discipline related needs and traditions. All of this can only be achieved by close collaboration between IT experts and domain scientists. COOPEUS partners have worked for the community building for the recent years and there are plenty of expertise and knowledge on cultural change that can be shared and learn from each other's.

Finding 12: Building common language and creating culture of open science

Increased collaboration and cross-cutting science also requires that scientists from different disciplines speak the same language. Terminologies of the different RIs need to be harmonized, or at least well documented, to enable easy use of datasets across the different user groups. Data discovery and correct use is strongly dependent on the users' ability to understand the context of the datasets. The development of dictionaries, ontologies and standardized terminology are specific tasks, but the change must come from the scientists themselves, who need to understand the need of providing documentation with their data in the common terminology, and the need to understand the terminology to find correct information. COOPEUS can be a strong activity in this field, combining the efforts in EU and US towards more standardized metadata and naming conventions. Cultural capital can be developed also by creating culture of open science. Quality-checked open data together with data indices and citation standardization forms the basis for open science culture. Good examples of open data sharing, such as web-services, already exist. Common language, in turn, is needed to ensure that people can understand each other. To be able to build a functioning culture of open science, it is relevant for scientists in different disciplines to see the benefits of the multidisciplinary and cross-disciplinary collaboration. Virtual use cases could be one way to demonstrate the value of the cross-disciplinary work.

Imperative and frontiers: All the above-defined actions (imperatives and frontiers) in the Strategic Goals will promote the building of common language and creating culture of open science. In addition, COOPEUS partners to disseminate COOPEUS outcomes and constantly invite new RI communities to join the COOPEUS community.

Finding 13: Ethical perspectives of the data

(text to be written)

4.3.3 Institutional framework

Preamble: Building communities is about building trust, creating person-to-person connections, having joint meetings and sharing ideas. COOPEUS as a community has a goal to sustain and develop research infrastructure collaboration on pursuing common and well-defined scientific objectives between EU and US in the environmental field in a longer timescale than a typical EC project lasts. Thus, there is a need for analysing and setting-up the effective and efficient organisation model for the long-term collaboration. During the COOPEUS EC-project, some of the organisational models have preliminary been discussed and evaluated.

Finding 14: Common long-term COOPEUS platform

COOPEUS was established in 2011 with the support from European Commission and year later followed by the support from US National Science Foundation. The last three years are proven the value of the collaborative work, however, it has also shown that changing the technical, human and cultural cultures will the time and the long, journey has just started. Therefore, it is a necessary to sustain common COOPEUS platform for future.

Imperative: COOPEUS partner RIs have defined several steps how to sustain the COOPEUS platform while seeking new funding opportunities for the collaboration. COOPEUS will start with the personal commitment statement. This statement engages partners at the person level to continue working as a group on the promotion of the COOPEUS outcomes and future activities. The next step towards long-term collaboration and strengthening the commitment of partners, and also as a more formal way to set the common rules of data sharing and inviting new partners to the community, is to establish new contractual relations among the COOPEUS partners (after the EC-project Consortium agreement is not valid anymore). The COOPEUS partners have discussed different types of agreement models, such as models of common Memorandum of Understanding / Letter of Understanding / Letter of Intent or setting-up an association on a voluntary basis for facilitating the activities of the COOPEUS community. As a deliverable of the Work Package 7, a template of the COOPEUS Memorandum of Understanding (MoU) was formulated to take this step forward in the community. The focus of the drafted COOPEUS MoU template was on supporting collaboration between research infrastructures in the field of scientific and technical developments. The development of a more formalised collaboration agreement will take some time. Meanwhile the collaboration action could be partially implemented through existing, already funded initiatives and projects. For example, ENVRI^{PLUS} could offer a short-term link between COOPEUS US and EU partners, as the current funding support for the European partnership will soon come to an end. For instance, BEERi (Board of European Environmental Research Infrastructures organized by ENVRI^{PLUS}) meetings could be the place for US colleagues to follow the European RI developments. In addition, some support could be provided at least for the transatlantic marine collaboration via ODIP – project (integrating regional marine data infrastructures for global ocean science).

Imperative: COOPEUS partners to seeking international / transatlantic funding opportunities to sustain the core activities of the COOPEUS platform to start working on the defined **Findings**.

Finding 15: Expansion of collaborative work and governance structure beyond Europe-US

Globally, large amounts of environmental data observed are not connected to the international data management systems. The challenges are mostly related to the cultural, technical and resource barriers that can be overcome with closer collaboration, training, dissemination and task sharing. There is a large wellspring of other organizations and research infrastructure around the globe that are starting to face the same challenges COOPEUS is tackling. Many of the COOPEUS partners are already organising workshops, training courses and other dissemination activities e.g. in Asia, Latin America, and Africa related to data management and federated data services. COOPEUS provides an excellent entry point to these e-informatics forums. COOPEUS can facilitate the wider collaboration among research infrastructures in their international training activities by going beyond bilateral workshops and courses to shared international knowledge transfer activities. Implementing this finding will enable better data discovery, access and usability of these yet not well-connected data sets and databases to the international data systems. The effort would increase the amount of data available globally. In some cases US and EU research infrastructures may also support the maintenance of the data seta and databases by providing backup systems or replication services for the communities that are suffering severe resource limitations. Moreover, the governance structure for COOPEUS for Phase 1 can be adapted to include new work tasks and international partners.

Imperative: COOPEUS RI partners to continue to engage and seek opportunities with other international organizations towards broadening participation, advancing strategic goals, and building additional capacity.

Imperative: Dynamically adapt current governance structures to accommodate new organizations (international entities, RI, federal agency programs, NGOs, and other funded projects). Continue having a bureaucratically light governance structure that works with- and response to bottom-up stakeholder input.

4.4 Strategic Goal 4: Contribute to address evolving societal and scientific needs by providing information on Earth System – Implementing Scientific Field-Specific COOPEUS Use Cases

Preamble: During the discovery (First Funding) Phase for COOPUES, as a thought experiment, COOPEUS developed use cases the would utilize data from 2 or more of the WPs to ask novel, cross-discipline questions. We did this to inform what may be needed to advance the harmonization of data, i.e., to identify building blocks, new controlled vocabularies, IPR, open data policies etc. This was a very productive exercise, and as such, implementing such use cases will further advance the COOPEUS Strategic Goals, especially by contributing to the Strategic Goal 4 on providing information on Earth system. Note: that these Findings/Use Cases/Imperative are not mutually exclusive in meeting Strategic goals but serve as a examples for future collaborative work in where the several aspects of the data interoperability can be tested and enhanced.

Finding 16 Use Case: Harmonization of Tsunami Data and Warning Processes

This Finding/Use Case covers the marine and solid Earth domains and is relevant both for Cross-Atlantic and for global collaboration. The harmonization of the tsunami data and warning processes have high user benefit as the intercomparison, access and alignment of the data processing activities will result in easier and faster data handling from various data sources and enhances the interpretation of the results. Participative research infrastructures will benefit from the interoperability assessment, harmonisation of the data protocols and processes and support the sharing of expertise and best practises.

Imperative: To achieve the harmonised tsunami data and warning system, this use case requires following subtasks; i) comparison of metadata (incl. instrument details, calibrations, configurations and site details), ii) comparison of data QA/QC protocols, and iii) common analysis of data (using each approach and algorithms, comparison of pre-analysis protocols, run tsunami detection algorithms on same data, compare results); comparison of operational models to execute joint algorithms, e.g., how to run algorithms?, is there a need for upload the data or results?, what is the basis to integrate new instrument and/or algorithms into the analysis?

Frontier: (TBD)

Finding 17 Use Case: Expansion of federated services beyond Europe-US (Solid Earth)

This Finding/Use Case covers the solid earth and seismological communities (outside COOPEUS Partners) are also mature in their organizational approaches to the harmonization of data. IRIS has already supported the inclusion of FDSN web services into a turnkey seismic network operating system. Modest effort would bring together a broader international community and advance Strategic Goal 1, and distribute this turnkey system.

Imperative: Being able to federate services will increase the amount of data available globally—to other solid earth and seismological organizations with identical and harmonized data formats and through identical access mechanisms easing data discovery, access and usability. Partner ready to adopt this system and federate data include seismic data centres in the Latin American and Asian regions.

Finding 18 Use Case: Data – Model Fusion by linking the temporal information embedded in local-to-regional phenology (Biodiversity) to advance Ecosystem Production Model Fidelity (Carbon)

Current Earth System models have very well defined model structure and the processes governing ecosystem carbon dynamics. However, when compared to in-situ data behave poorly due to their inability to capture the timing of key seasonal event (phenology), such as, leaf out, root flush, peak productivity, flowering and reproduction, onset of summer drought, onset of senescence. This provide a unique case study to merge earth-system modelling with in-situ observations of phenology, and bring together the carbon and biodiversity communities in novel ways to advance our understanding of these

processes.
Imperative: Compare the different sources of phenology observations, as well as the technical issues like different formats, conventions or quality assurance methods, employed in EU and US. Describe the methods used to access data.

4.5 Towards global collaboration

Globalization creates an increasingly interconnected world. These rapid, large-scale, global environmental changes have emphasized the value of long-term, globally distributed data sets to understand the context of scientific observations and to forecast future conditions. The science communities are entering an era of large-scale, interdisciplinary science driven by large data sets that will be analyzed by current and future generations, alike. A myriad of high-level (international) governmental planning documents have called for the interoperability of large-scale datasets to inform policy and benefit society. COOPEUS provides an international roadmap to achieve these goals, and is a known and trusted partner working internationally. Hence, we recognized the need for increased and enhanced global collaboration.

Increased and enhanced global collaboration in the context of meeting COOPEUS Strategic Goals also enables new scientific and societal frontiers. Chiefly, COOPEUS will be able to ask new questions for scientific and societal importance that;

- ***span cross-disciplines*** that have not been able to be asked previously. Some are highlighted as use cases above, but because this scientific opportunity is still nascent, most are yet to be realized.
- for the first time ever, COOPEUS will be able ***to make cross-continental comparisons***. That is to say, we will be able to compare, contrast, understand, and predict the underlying processes of environment change. For example, we know the inception and development of drought in China, Australia, US and Europe differ, but we do not understanding the underlying processes and the feedback to food security.
- there are exogenous drivers, ***teleconnections*** outside our continental-to-cross continental boundaries that affect the environmental processes therein (*i.e.*, synchrony, the spatial and temporal connectivity of one ecological event that contributes to other ecological processes). A common example is how El Niño oscillations control and telecommunicate climate patterns across large regions of the earth affecting ecological processes. In other words, in an ever increasingly connected global world, the environmental horizons need to look beyond classic boarders to examine causal processes, particularly in light of changing synoptic climate, new migrations, and human mediated changes in mass and energy flows.

Because COOPEUS has taken international leadership, there is increased interest of—and need to partner with other environmental research Infrastructures and organizations and geopolitically broaden our scope. We have identified these in the Strategic goal 1 and the COOPEUS's governance structure is designed to adapt in order to accommodate other partners. Other international organizations, as well have expressed strong interest in becoming part of COOPEUS. In particular, wider collaboration with Canada, Australia, Asian, and circumpolar organizations. Many of the COOPEUS partners have already international collaboration and are moving towards deeper international work.

Programmatic activities that foster these collaborations are ***seeking formal agreements***. Typically these take the form of Memorandum of Understanding (or similar structures) (MOU) that outline the nature of the associated partnership and collaboration. MOUs are designed to mirror the COOPEUS strategic Goals. Few MOUs have been crafted and signed already, and have been productive. More broader and encompassing bi-lateral agreements should also be considered.

Lastly and importantly, the success of COOPEUS in meeting its strategic goals is to ensure that the ***adequate support and resources*** – both human and funding. We call for collaboration with partnership organizations to jointly seek support, and that all organizations should have adequate resources concurrently to avoid situations where the participation is not possible to all situations from either side.

5. Timeline for COOPEUS roadmap implications

Table 3. This table gathers the COOPEUS identified actions from the section 4: Roadmap – implementing COOPEUS mission and categorise them in to short-term (imperative) and long-term (frontier) actions. Note, the order of the listing does not prioritise the actions.

Short-term/Imperative	➢ ***Finding 1**: **Common description of data systems*** ➢ To increase our knowledge of all the partners and related data providers' data management systems ➢ ***Finding 2: Collaborative advancement on Standards and Metrology*** ➢ To develop a community driven forum, and in partnership with standards holding bodies ➢ ***Finding 3:* Supporting the common data licenses following Creative Commons standards** ➢ A COOPEUS action for comparing currently used licenses and support of the commonly acceptable Creative Common standard for research infrastructures is suggested for the future collaboration. ➢ ***Finding 4:* Long-term preservation and certification of Research Infrastructure Data Centers** ➢ Mapping the COOPEUS partner RIs' plans on the long-term preservation and seeking optimised international solutions for Earth system science data for long-term preservation. ➢ Implementation of Geodetic Seamless Archive Centers (GSAC) software system (or API) by EPOS. ➢ Support the full implementation of GSAC to the remaining EPOS institutions, and advance the use and future development through technical workshops such as the 2014 GSAC workshop in Portugal, and community forums. ➢ ***Finding 5: Advance the use of standard methodologies for use of Persistent Identifiers*** ➢ This should be done in conjunction with larger interdisciplinary COOPEUS activity on data citation methodology, and broad engagement of other (domestic) organizations, e.g., ESIP, RDA, Belmont, Forum, ENVRI^{plus}, etc. ➢ ***Finding 6: Creating interoperable Quality Assurance and Quality control (QA/QC) Methodologies*** ➢ To identify the needed QA/QC approaches to manage joint uncertainties in data across the respective science fields, and develop and implement joint QA/QC plans. ➢ While this is limited to solid earth and specifically seismological data types, IRIS and COOPEUS partners will foster coordination of QA efforts within the FDSN (International Federation of Digital Seismograph Networks) in order to harmonize the approach to QA metrics across the FDSN members.

	➢ ***Finding 7: Develop, promote sound, and execute defensible Data Management plans and archival guidelines***
	  ➢ TBD
	➢ ***Finding 8: training of Research Infrastructure users***
	  ➢ Enhance the collaboration among the COOPEUS RIs on the user training by sharing best practises on organising training events and teaching methods.
	➢ ***Finding 9: Training of staff and staff exchange***
	  ➢ Research infrastructures can also support the staff mobility and building-up new career pathways via staff exchange programs and targeted cross-RI staff training courses (e.g. physical and online courses, webinars).
	➢ ***Finding 10: Citizen Science***
	  ➢ COOPEUS can provide a platform where the different experiences and knowledge can be shared among RIs.
	➢ **Finding 11: Communication strategy**
	  ➢ Novel, easy and quick access to the new integrative tools is also vital, which implies that IT community should be involved in the development of new set of tools, however, the IT experts should carefully listen and respect the discipline related needs and traditions.
	➢ **Finding 12: Building common language and creating culture of open science**
	  ➢ All the above-defined actions (imperatives and frontiers) in the Strategic Goals will promote the building of common language and creating culture of open science.
	➢ **Finding 13: Ethical perspectives of the data**
	  ➢ TBD
	➢ **Finding 14: Common long-term COOPEUS platform**
	  ➢ COOPEUS partner RIs have defined several steps how to sustain the COOPEUS platform while seeking new funding opportunities for the collaboration.
	  ➢ COOPEUS partners to seeking international / transatlantic funding opportunities to sustain the core activities of the COOPEUS platform to start working on the defined **Findings**.
	➢ ***Finding 15: Expansion of collaborative work and governance structure beyond Europe-US***
	  ➢ COOPEUS RI partners to continue to engage and seek opportunities with other international organizations towards broadening participation, advancing strategic goals, and building additional capacity.
	  ➢ Dynamically adapt current governance structures to accommodate new organizations (international entities, RI, federal agency programs, NGOs, and other funded projects).
	➢ ***Finding 16 Use Case: Harmonization of Tsunami Data and Warning Processes***
	  ➢ To achieve the harmonised tsunami data and warning system.

	➢ ***Finding 17 Use Case: Expansion of federated services beyond Europe-US (Solid Earth)*** ➢ Being able to federate services will increase the amount of data available globally—to other solid earth and seismological organizations with identical and harmonized data formats and through identical access mechanisms easing data discovery, access and usability. ➢ ***Finding 18 Use Case: Data – Model Fusion by linking the temporal information embedded in local-to-regional phenology (Biodiversity) to advance Ecosystem Production Model Fidelity (Carbon)*** ➢ Compare the different sources of phenology observations, as well as the technical issues like different formats, conventions or quality assurance methods, employed in EU and US. Describe the methods used to access data.
Long-term/frontiers	➢ ***Finding 1***: ***Common description of data systems*** ➢ To better understand the needs and develop (accordingly) the different data quality indicators (data processing steps and data level definitions) and on service provision of high-level data products needed by the research infrastructures. ➢ ***Finding 2: Collaborative advancement on Standards and Metrology*** ➢ Jointly develop the international discourse and forum to advance these Findings ➢ ***Finding 3:*** **Supporting the common data licenses following Creative Commons standards** ➢ Jointly develop the international discourse and forum to advance these ***Findings***. ➢ ***Finding 4:*** **Long-term preservation and certification of Research Infrastructure Data Centers** ➢ Certify all COOPEUS data centres as WDS certified data centres (and in the case of renew the certification of the IRIS DMC). ➢ ***Finding 5: Advance the use of standard methodologies for use of Persistent Identifiers*** ➢ Jointly develop the international discourse and forum to advance these ***Findings***. ➢ ***Finding 6: Creating interoperable Quality Assurance and Quality control (QA/QC) Methodologies*** ➢ RIS will introduce this concept at the FDSN meetings in 2015 in Prague (IUGG meeting). ➢ Respective COOPEUS RIs (Carbon, Oceans, Solid Earth, Seismology, Biodiversity, Space Weather) to foster this discourse in respective international forums, and search resources to advance this Imperative, e.g., IRIS to introduce this concept at the FDSN meetings in 2015 in Prague (IUGG meeting). ➢ ***Finding 7: Develop, promote sound, and execute defensible Data***

	Management plans and archival guidelines ➢ TBD ➢ ***Finding 10: Citizen Science*** ➢ Activities should estimate the signal-to-noise ratio for the observed Citizen Science data. ➢ **Finding 12: Building common language and creating culture of open science** ➢ All the above-defined actions (imperatives and frontiers) in the Strategic Goals will promote the building of common language and creating culture of open science. ➢ **Finding 13: Ethical perspectives of the data** ➢ TBD ➢ ***Finding 16 Use Case: Harmonization of Tsunami Data and Warning Processes***

6. Summary of COOPEUS roadmap

Oliver Gilles: Collaboration between RIs is really making EU and US research communities closer together.

The principal objective of COOPEUS is to remove the barriers to interoperability in the environmental sciences in order to expand scientific discovery and improve predictive capacity. COOPEUS have done this by established a governance structure (**WP1**), broadly survey and assess current needs and knowledge gaps that can inform an implementation plan (**WP7**), culminating in a joint framework (**WP8)** (this roadmap document). All the activities in COOPEUS (**WPs 1-7)** lead to the synthesis activities in this document. Both the 'knowledge gap' synthesis and implementation plan is part of 'the COOPEUS roadmap'. The 'knowledge gap' includes a ***robust landscape analysis*** of how all the different environmental research infrastructures map to a broader landscape of disciplines and data products and also categorizes them by institutional mandate (top down directives) and organizational structure. This allowed us to define the nature of the interactions and interfaces that could be possible among RIs. ***The implementation plan*** is crafted in terms of a strategic plan, with 'findings', 'imperatives', and 'frontiers'. This implementation plan will allow us to well define the actions needed to initiate interoperability and the harmonization of data across environmental research infrastructures. It is designed to clearly communicate the prioritization of activities to sponsors, new participants, and current partners, alike. A living version of the COOPEUS roadmap will be made available publically September 30, 2015.

This Project also recognizes that these efforts cannot be done in a vacuum. Hence, broad inclusion and engagement with a strong international (European) partners (e.g., mentioned above, and WMO, GEOSS, Future Earth, GEO, Belmont Forum), informatics forums (e.g., EarthCube, ESIP, RDA, EUDAT, DataONE, ODIP, etc.), US federal agencies and agency programs (e.g., NOAA GMD, DOE AmeriFlux, USGS BISON, USGS Powell Center, NCEAS) has been the focus of all our activities. In '***broad inclusion and engagement'***, COOPEUS also recognize the need to build and change the culture of sharing data and interoperability. As such, ***COOPEUS has made great strides in bringing EU and US (and beyond) research communities, research infrastructures closer together***.

APPENDIX 1. List of acronyms

ACTRIS	EU FP7 Aerosols, Clouds, and Trace gases Research InfraStructure Network, Grant Agreement n. 262254 (2011-2015)
AmeriFlux	A network of PI-managed sites measuring ecosystem CO_2, water, and energy fluxes in North and South America
AMISR	Advanced Modular Incoherent Scatter Radar
ANAEE	A European research infrastructure on Analysis and Experimentation on Ecosystems
ARISE	Atmospheric dynamics Research InfraStructure in Europe
ASSEMBLE	Association of European Marine Biological Laboratories
Belmont Forum	The Council of Principals for The International Group of Funding Agencies for Global Change Research
Biofresh	A freshwater biodiversity information platform
COOPEUS	Cooperation EU +US: Strengthening the cooperation between the US and the EU in the field of environmental research infrastructures - A program supported by the European Union in cooperation with the NSF
CUAHSI	The Consortium of Universities for the Advancement of Hydrologic Science
DataONE	Data Observation Network for Earth
DDAC/DAC	Drifter Data Assembly Center assembles and provides uniform quality control of sea surface temperature (SST) and surface velocity measurements
DEDI	Directory of Entomology Departments and Institutes
DEISM	Distributed European Infrastructure for Subseafloor Sampling and Monitoring
DoE-ARM	The Department of Energy Atmospheric Radiation Measurement
EarthCube	A joint initiative between the National Science Foundation (NSF) Directorate for Geosciences (GEO) and the Division of Advanced Cyberinfrastructure (ACI), envisions a dynamic, community-driven cyberinfrastructure that supports standards for interoperability, infuses advanced technologies to improve and facilitate interdisciplinary research, and helps educate scientists in the emerging practices of digital scholarship, data and software stewardship, and open science.
EARTHSCOPE	A scientific community conducts multidisciplinary research across the Earth sciences utilizing freely available data from instruments that measure motions of the Earth's surface, record seismic waves, and recover rock samples from depths at which earthquakes originate
ECORD	European Consortium for Ocean Research Drilling
EISCAT	The European Incoherent Scatter Scientific Association
EISCAT-3D	The Next Generation Radar for Atmospheric and Geospace Science
ELIXIR	A distributed infrastructure for life-science information
EMBRC	The European Marine Biological Resource Centre
EMODNET	The European Marine Data and Observation Network
EMSC	Euro-Med Seismological Centre
EMSO	European multidisciplinary seafloor & water column observatory
ENVRI	EU FP7 Common Operations of Environmental Research infrastructures, Grant Agreement n° 283465 (2007-2013)
$ENVRI^{PLUS}$	Horizon 2020 cluster project on Environmental Research Infrastructures Providing Shared Solutions for Science and Society
EPOS	European Plate Observing System
ESFRI	European Strategy Forum on Research Infrastructures
ESIP	The Federation of Earth Science Information Partners
EUDAT	Research Data Services, Expertise & Technology Solutions
EUFAR	EU FP5/FP6/FP7 European Facility for Airborne Research

EURO-ARGO	European contribution to Argo program, the broad-scale global array of temperature/salinity profiling floats
EUROCHAMP	Integration of European Simulation Chambers for Investigating Atmospheric Processes
EUROFLEETS2	EU FP7 New operational steps towards an alliance of European research fleets
EuroGeoSurveys	The Geological Surveys of Europe, not-for-profit organisation representing 33 National Geological Surveys and some regional Surveys in Europe
FDSN	International Federation of Digital Seismograph Networks
FIXO3	Fixed-Point Open Ocean Observatories
Future Earth	International research platform providing the knowledge and support to accelerate our transformations to a sustainable world
GBIF	Global Biodiversity Information Facility
GEO, GEOSS	Group on Earth Observations, The Global Earth Observation System of Systems
GEOS-Seas	Pan-European infrastructure for management of marine and ocean
GMOS	Global Mercury Observation System
GNSS	Global Navigation Satellite System
GROOM	Gliders for Research, Ocean Observation and Management
GSAC	Geodetic Seamless Archive Centers
IAGOS-ERI	European Research Infrastructure on In-service Aircraft for a Global Observing System
ICDP	International continental Scientific Drilling Program
ICOS	Integrated Carbon Observation System Research Infrastructure
ICSU	International Council for Science
IGFA	The International Group of Funding Agencies for Global Change Research
i-Marine	Data e-Infrastructure Initiative for Fisheries Management and Conservation of Marine Living Resources
INCREASE	An integrated Network on Climate Research Activities on Shrubland Ecosystems
InGOS	EU FP7 Integrated non-CO2 Greenhouse gas Observation System, Grant Agreement n° 284274 (2011-2015)
INTERACT	International Network for Terrestrial Research and Monitoring in the Arctic
InterMagnet	The global network of observatories, monitoring the Earth's magnetic field
IODP	International Ocean Discovery Program
IRIS	Incorporated Research Institutions for Seismology
IRIS DMC	IRIS Data Management Center
IS-ENES	Infrastructure for the European Network for Earth System Modelling
IUGG	The International Union of Geodesy and Geophysics
JERICO	A joint European research infrastructure network for coastal observatories
LacCore	Latin American and Caribbean Council on Renewable Energy
LifeWatch	E-Science European Infrastructure for Biodiversity and Ecosystem Research
LP DAAC	The Land Processes Distributed Active Archive Center
LTAR	Long-Term Agroecosystem Research Network
LTER	The Long Term Ecological Research Network
Madrigal	An upper atmospheric science database
MESOAQUA	Recent achievements and future directions in Aquatic Mesocosm Research
MIRRI	Microbial Resource Research Infrastructure
NAIC	The National Association of Insurance Commissioners
NASA	National Aeronautics and Space Administration
NCAR	The National Center for Atmospheric Research
NCEAS	The National Center for Ecological Analysis and Synthesis
NEON	National Ecological Observatory Network, research Infrastructure funded by NSF
NERA	Northeastern Educational Research Association
NICL	The U.S. National Ice Core Laboratory
NOAA	National Oceanic and Atmospheric Administration
NOAA GMD	National Oceanic and Atmospheric Administration Global Monitoring Division

NOAA/NCDC	The National Oceanic and Atmospheric Administration, formerly the National Climatic Data Center
NOAA-NDBC	The National Data Buoy Center (NDBC) is a part of the National Oceanic and Atmospheric Administration's
NOAA-NGDC	National Geophysical Data Center is part of the National Oceanic and Atmospheric Administration's
NOAO	The National Optical Astronomy Observatory
NORS	EU FP7 Demonstration Network Of ground-based Remote Sensing Observations in support of the Copernicus Atmospheric Service, Grant Agreement n°284421
NRAO	The National Radio Astronomy Observatory
NSF	National Science Foundation, primary US funding agency for primary research, education and research infrastructure
NSIDC	The National Snow and Ice Data Center
ODIP	Ocean Data Interoperability Platform
OneGeology	An international initiative of the geological surveys of the world
OOI	Ocean Observatories Initiative, research Infrastructure funded by NSF
ORNL-DAAC BD	The Oak Ridge National Laboratory Distributed Active Archive Center
PESI	Pan-European Species-directories Infrastructure
PGC	the Polar Geospatial Center
RDA	Resource Description and Access
Scripps-GDC	The Geological Data Center in Scripps
SDSC	the San Diego Supercomputer Center
SeaDataNet	The SeaDataNet infrastructure links already 90 national oceanographic data centres and marine data centres from 35 countries riparian to all European seas
SIOS	Svalbard Integrated Earth Observing System
SPECIES2000	Species 2000 is an autonomous federation of taxonomic database custodians, involving taxonomists throughout the world.
SYNTHESYS	the European Union-funded Integrated Activities grant which aims to produce an accessible, integrated European resource for research users in the natural sciences
UNAVCO	A non-profit university-governed consortium, facilitates geoscience research and education using geodesy
US-ARGO	The US contribution to Argo program, the broad-scale global array of temperature/salinity profiling floats
USFS	The United States Forest Service
USGS	U.S Geological Survey
USGS-BISON	The USGS Biodiversity Information Serving Our Nation
USGS-EROS	The USGS the Earth Resources Observation Systems
USGS LPDAAC	The Land Processes Distributed Active Archive Center, located in USGS-EROS
WISEMarine	The Water Information System for Europe
WMO	World Meteorological Organization
WoRMS	World Register of Marine Species