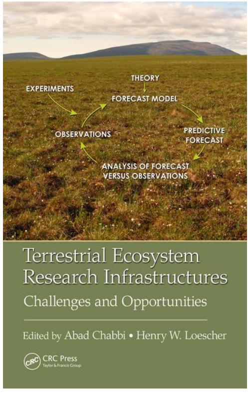

Terrestrial Ecosystem Research Infrastructures Challenges and Opportunities

Abad Chabbi, Henry W. Loescher

Community-Driven Efforts for Joint Development of Environmental Research Infrastructures

Publication details
https://www.routledgehandbooks.com/doi/10.1201/9781315368252-18
Abad Chabbi, Henry W. Loescher, Ari Asmi, Magdalena Brus, Sanna Sorvari
Published online on: 22 Feb 2017

17

Community-Driven Efforts for Joint Development of Environmental Research Infrastructures

Ari Asmi, Magdalena Brus, and Sanna Sorvari

CONTENTS

17.1 Introduction

17.1.1 Challenges in the Earth System

The earth is a highly complex system, formed by a large variety of subsystems, such as the biosphere, atmosphere, hydrosphere, and lithosphere, interacting by the exchange of energy and mass. All of these domains are highly interlinked, with many concurrent processes operating on a wide range of temporal and spatial scales. Many natural processes are self-organizing, giving rise to a high degree of variety and complexity in the system (Rial et al., 2004). At the same time, the earth system and human society are facing global environmental and societal challenges, many of which are not particular to any one of the domains (Figure 17.1). We can only understand, predict, and possibly solve them if we understand the systems where they originate. This is

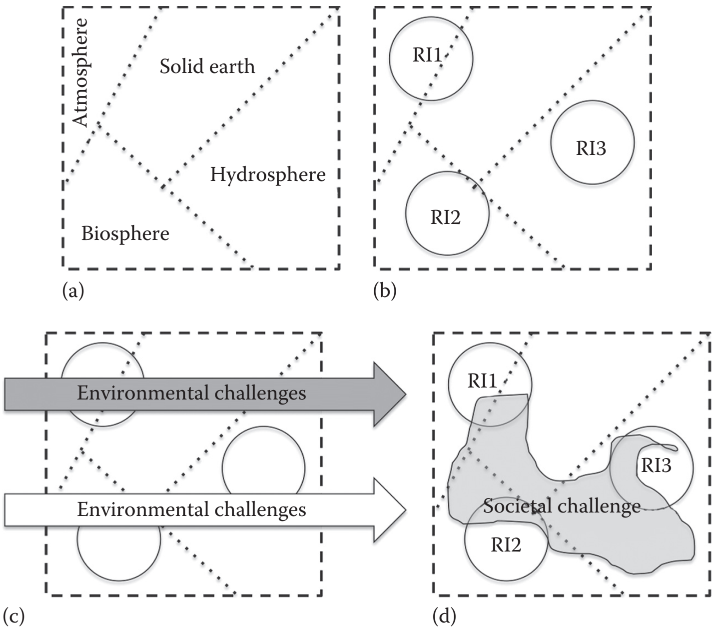

FIGURE 17.1
Cross-disciplinary challenges of environmental research. (a) Earth system is often considered (and researched) from the viewpoint of Earth system domains; (b) infrastructures do not capture the full field of potential research and often do not cover only one domain; (c) environmental challenges do not follow the boundaries or either domains of the research infrastructures; (d) societal challenges create yet another layer of complexity to the system, increasing the need to use different research infrastructures in unison. No single research infrastructure will be able to answer to the environmental or societal challenges—interoperability of the research infrastructures is crucial to get any answers to these challenges.

not possible without environmental research and its supporting global-scale data delivery with analyses from observations, experiments, and modeling.

For the earth system, as for any system, our capacity to understand is predicated on our capability to observe, analyze, and model the earth's subsystems and their interactions. Understanding our environment is not possible by simply extrapolating a given process from the single components of which it is composed (Donner et al., 2009). A different approach is needed—a *systems approach* (Steffen et al., 2001). The efforts to minimize the negative impacts of human activities on environment will only be successful if it is based on holistic knowledge and adequate predictive capabilities. By carefully exploring and studying the basic environmental processes in relevant time and spatial scales and synthesizing our observations into an overall understanding, new scientific breakthroughs can be achieved and environmental challenges can be tackled. However, acquiring such information requires long-term, standardized, openly available, well-documented, and trustworthy observations of the earth system.

17.1.2 Environmental Research Infrastructures

There is a clear evidence of the need to build a global integrated observing system for environmental sciences covering all the domains of the earth system (Houghton et al., 2012). Environmental research infrastructures with their service provision, especially on the delivery of observational data, represent an irreplaceable part of this system (OECD, 2010). They have a significant global role as knowledge providers, bringing together a wide variety of stakeholders to search for solutions to their own specific scientific problems. Indeed, most of the current environmental infrastructures were initially established separately from each other to serve a specific science community and therefore did mainly focus on limited aspects or phenomena of the earth system. The interlinked nature of the earth system however requires better organization of the research infrastructure landscape and scientific communities to transcend the well-established and familiar boundaries of disciplines and domains and work toward common holistic understanding of the environment as one system. Significant efforts toward the interoperability and harmonization of research infrastructures' operations must be taken to address today's environmental challenges.

This and the following sections are concentrated on the European research infrastructure development based on the authors' expertise and experiences. Even though the projects and initiatives are mostly European funded, the overall challenges seem to be largely usable to the other areas of the world as well, as demonstrated in the EU–U.S. research infrastructure projects (COOPEUS and COOP+; see Sections 17.2.2 and 17.4.2).

Most of the pan-European environmental research infrastructures are currently being built, and some are more matured than others. It is crucial to bring them together, to share the knowledge and to develop common solutions at all stages of their development—in their planning, design, construction, and operation to ensure their interoperability and to avoid unnecessary costs and duplication of efforts.

17.1.3 Environmental Research Infrastructure Development in Europe

There is no single accepted definition of "research infrastructure," as the term can mean different things in the different fields of science and in different regions even inside the same field. It is indeed a challenge to provide a comprehensive definition including all the elements of the research infrastructures and at the same time distinguish them enough from the other existing research facilities and organizations.

The most used definition in Europe is the one of European Strategy Forum on Research Infrastructures' (ESFRI), defining research infrastructures as "facilities, resources or services of a unique nature that have been identified by research communities to conduct top level activities in their fields. They may be single sited, distributed or virtual."

In terms of tools, they provide unique instruments or libraries enabling researchers to perform an excellent science. This can be, for example, telescopes when talking about astronomy, colliders in physics, observatories, and databases in the context of environmental sciences or biobanks in the field of life sciences.

The research infrastructures are changing the way in which the research is conducted by providing access to escalating amounts of data, by methodological innovation and novel approaches with respect to how data are gathered and used. Besides the key tools and services they provide to its scientific community, they also play an increasingly significant role in the dissemination of knowledge, scientific information, and know-how by way of training and network building. They propel cooperation across the scientific fields and national borders. By this, they are structuring the scientific community and play a key role in the construction of an efficient research and innovation environment in Europe and beyond.

Research infrastructures differ from other research facilities (Table 17.1) by their focus on providing the services, ability to gather the critical mass of people, knowledge, and funds. Long-term funding, together with a sustainable governance model and legal framework, ensures the long-term stability of the infrastructure and better possibility for strategic development and collaboration with other infrastructure facilities (e.g., on e-infrastructure side).

Research infrastructures are not a new approach to "big science." Many other scientific disciplines cannot conduct research otherwise. Such as the researchers in astronomy (e.g., European Southern Observatory, founded in 1962) or high-energy physics (e.g., European Organization for Nuclear Research, CERN, f. 1954) have, for example, required major international infrastructures also for practical reasons: the large investments needed to build and operate a research infrastructure are too large for any single

TABLE 17.1

Simplified Typical Features of Different Public Research Components

	University Research	Research Institutions	Research Infrastructure
Typical funding model	Projects	Projects and institutional funding	Governmental strategic funding
Typical time period of activity	Short (1–4 years)	Medium to long term	Long term
Main contribution to scientific process	Education of researchers, cutting-edge research	Medium- to long-term continuity in research, operational research, applied research	Maintaining the research capabilities and prerequisites (instruments, standards, policies)

Source: Adapted from Asmi, A. et al., ERIS—Environmental Research Infrastructures Strategy for 2030, ENVRI project publication, DOI:10.6084/m9.figshare.2067537, 2014.

European country to support it alone. There are also philosophical and political reasons for such cooperation, envisioning European states working together and in a coherent manner.

However, the mechanisms to build such international major collaborations needed many ad hoc legal and contractual solutions, making the overall institutional development a long and arduous process (Hermann et al., 1987). A more collective and uniform process for common research infrastructure development was needed.

In 2002, the Commission and the EU member states created ESFRI to support a "coherent and strategy-led approach to policy-making on research infrastructures in Europe." This process has created a specified pathway to create, develop, and evaluate pan-European research infrastructures, with ESFRI roadmap being a key instrument.

17.1.3.1 ESFRI Roadmap

The ESFRI roadmap identifies projects for implementation of new research infrastructures (or major upgrade on existing ones) based on their scientific excellence, pan-European relevance, and, the newly considered, socioeconomic impact. A growing number of countries have prepared national roadmaps in order to prioritize the national and pan-European research infrastructures, using the ESFRI roadmap as a reference. This helps the countries to define their national budgets, to facilitate the political support, and to allow a long-term financial commitment.

The ESFRI roadmap is an ongoing process. Nine research infrastructures from the environmental field were included in the last update of the roadmap in 2010 and some of the ecology-related infrastructures, for example, research infrastructure for experimental manipulation of managed and unmanaged terrestrial and aquatic ecosystems (ANAEE, www.anaee.com) and European Marine Biological Resource Center (www.embrc.eu) were also included from the biological and medical science field. The next update of the roadmap will be launched in 2016. It should be noted that even though the ESFRI organizes the strategic development and prioritization, it is not a funding agency. The main funding responsibility in the construction and operational phase lies in the member countries of the research infrastructure (EU member states). Regional structural funds from the EU and European Investment Bank funding instruments may provide additional sources of funding in the construction phase of the research infrastructures. In addition, the European Commission (EC) provides support for the pan-European coordination of the research infrastructure implementation, for example, by providing project funding for research infrastructure planning and implementation (design study, preparatory phase project, implementation, and cluster-level funding support), through the Horizon 2020 funding program.

It is worth mentioning that inclusion in the ESFRI roadmap does not guarantee that research infrastructure will be actually built. Before the construction and/or implementation itself, many decisions need to be taken with respect to issues such as the identification of funders, the financial plan for sustainability, the governance by involved stakeholders, the site and legal form of the managing organization, the architecture, and the service policies.

As the main funding comes from the member states, many national roadmap processes and funding cycles and policies and decision-making processes need to be run and streamlined in order to establish a European-level budget for the research infrastructures. This requires good coordination and communication practices among the member states and between the stakeholders and science communities in charge of the research infrastructure implementation. With the national-level and EC support funding, the research infrastructure can be implemented; however, the main challenge is to receive the right type of support in the right moment of the process. Thus, it is a challenge of "valleys of death" if the right type of support is not available either at the national or European level when needed. This can cause unnecessary delays and loss of expertise.

17.1.4 Common Challenges in the European Research Infrastructure Field

Most infrastructures serve (or intend to serve) a broad community of researchers working in a particular field of research by providing core data and derived data products, and physical, virtual, and/or data access and computational services for the users that have not been previously available to that community or were operating on a limited project basis.

The design of each research infrastructure service provision was originally based on research infrastructure's main science communities; however, each research infrastructure is also providing its data and services to wider user communities and thus contributing to the wider, trans- and interdisciplinary science questions and grand environmental challenges regardless of its particular field of interest. Because of this broad accessibility across disciplines and user groups, many research infrastructures early and/or key discoveries were not necessarily the ones for which the original plans and design were intended.

There are many common challenges that most of the research infrastructures share, for example, the collection, preservation, archival, quality control, integration and availability of data, governance, policies, performance indicators, training of staff, user community interaction, and providing the computational capability to perform the analyses of interest to researchers. Moreover, while each research infrastructure is separately concerned with the integration of data within its own domain of interest, it is also imperative to find efficient means to integrate data and computation across research infrastructures and domains to serve an increasingly multidisciplinary scientific community. These kinds of common challenges, together with the scientific requirements to answer the earth system challenges, lead to joint collaborative projects between the research infrastructures.

17.2 The Beginnings of Collaboration

17.2.1 ENVRI Project (2011–2014)

After the publication of ESFRI roadmap 2008, it was evident that all the selected environmental research infrastructures will face similar challenges in their implementation and as all the environmental research infrastructures are contributing to the earth system science, the idea of closer collaboration among them was identified. In 2010, the EC launched the call for enhancing the research infrastructure collaboration within the certain science domain (cluster), and the target actions toward collaborative work were initiated. As an outcome of the collaboration that began in 2011, the EC funded a project to cluster the major environmental research infrastructures in the ESFRI roadmap. The main goal of ENVRI "Common Operations of Environmental Research Infrastructures" (Chen and Hardisty, 2014) was to implement harmonized solutions and draw up guidelines for the common needs of the environmental ESFRI projects, with a special focus on issues as architectures, metadata frameworks, data discovery in scattered repositories, visualization, and data curation.

The target of ENVRI project was on developing common capabilities including software and services of the environmental and e-infrastructure communities to enable multidisciplinary scientists to access, study, and correlate data from multiple domains for system-level research. The common standards, deployable services, and tools developed were to be adopted by each infrastructure as it progresses through its construction phase. Due to differences in maturity level among the different research infrastructures, the adoption and implementation of ENVRI solutions within the European environmental research infrastructures is in some cases still underway (see Section 17.4 for current projects).

The project developed a common reference model (ENVRI RM) created by capturing the semantic resources of each participating research infrastructure. The model established taxonomy of terms, concepts, and definitions, which provides a common language for communication to unify understanding. Fundamentally, the model serves to provide a universal reference framework for discussing many common technical challenges facing all the research infrastructures collaborating in the ENVRI project. By drawing analogies between the reference components of the model and the actual elements of the infrastructures (or their proposed designs) as they exist now, various gaps and points of overlap could be identified (Chen et al., 2013). ENVRI RM also helped research infrastructures to get a clearer and more transparent description of their complex data streams and data processing steps, thus clarifying the respective responsibilities in the research infrastructure's construction phase.

However, many long-term benefits stem from more "soft" side of the project: ENVRI has created the nucleus of collaboration and trust among the individual environmental research infrastructures, and common understanding of the importance of their integration and codevelopment. One of the main outcomes of ENVRI was the agreement on the joint vision and strategy for the future development of the (in situ) European environmental research infrastructures (see Section 17.3).

17.2.2 COOPEUS (2012–2015)

The infrastructure collaboration in the European environmental sector was boosted by yet another project funded by the EC. COOPEUS "Strengthening the cooperation between the US and the EU in the field of environmental research infrastructures" (Koop-Jakobsen et al., 2014) brought together European research infrastructures with their U.S. counterparts in order to stimulate the creation of a truly global integration of existing infrastructures.

The main activities in COOPEUS were more oriented toward direct collaboration between the same (or similar) field research infrastructures, especially on the e-infrastructure development. An interesting challenge of the project was that it was separately funded from the EU and the US sides, with different funding models and periods.

The COOPEUS did create a similar sort of communality through an inter-Atlantic collaboration. The project included some interdisciplinary work, especially in the form of a common roadmap for environmental research infrastructure collaboration in EU–U.S. axis. Strictly speaking, as of now (2016), the COOPEUS is not a "past project" in the U.S. side due to the different lengths of the projects in EU and the United States.

17.3 Strategy of the European Environmental Research Infrastructures

In the ENVRI project, it became clear that a common plan is needed to ensure a concerted development of the European research infrastructures in the future. The European environmental research infrastructures strategy (ERIS) was thus a major product of the project and led to more strategic collaboration between the participants. The following sections will summarize the strategy.

17.3.1 Vision of ERIS Document

The ENVRI community defined in the ERIS strategy (Asmi et al., 2014) common aims and goals for the future:

The vision for environmental research infrastructures for 2030 is aiming toward universal understanding of our planet and its behavior. This should result in the evolution of a seamless holistic understanding of the earth system, an environmental system metamodel*, a framework of all interaction processes within the earth system, from solid earth to near space. Scientists that within their own science contribute with data, models, instruments, algorithms, and discoveries should feel that this serves a greater good, namely, a contribution to this understanding.

This holistic understanding will make it possible to approach the entire earth system from different perspectives and choose the portions of the whole conceptual understanding, which are relevant to the problem to be solved. This approach makes it possible to do new and flexible services and answer environmental and societal challenges. Most importantly, this approach is also aiming to be complete: any emerging issues can be tacked on the framework of this understanding, enabling tuning and improvement of the understanding and building the connections to other scientific fields such as social sciences.

Environmental sciences are rapidly moving to become one system-level science, mainly because modern science, engineering, and society are

* A term model here is not to mean a *computational model*, even though that can be one realization. Here the term is meant to describe a self-contained and consistent contextual model, which describes our understanding of the system, its linkages, and feedbacks.

increasingly faced with complex problems that can only be understood in the context of the full overall system they belong to. There are several reasons and enablers for this shift:

- *Technology push*. Technology innovations on, for instance, detectors and sensors with ever-increasing resolution allow deep observations of scientific phenomena important for the better understanding of the whole system. Connection between these new observations and the whole earth system requires ways to integrate between the domains. In addition, information technology innovations, such as digitalization of collections, also unlock resources at a systems level.
- *Demand pull*. The questions scientists are faced with nowadays (not only arising from curiosity but also from policies, like IPCC, IPBES, and GEO/GEOSS and societal needs) can simply not be solved using the traditional sources of information. Without access to information from adjacent disciplines, the answers scientists can give will increasingly be partial and incomplete and therefore less groundbreaking or even useful.
- *Globalization*. Like in economics and society, science is experiencing an upscaling due to globalization. Establishing and managing big data and information repositories often demand an international effort. This can also be observed from the ever-increasing aggregation of research funding such as ESFRI.
- *Resource integration*. Never before did researchers of so many domains have such a wealth of resources at their disposal. The integration of these worldwide available resources has further fueled system-level research. An important contribution of e-science as a system-level science is its potential for integration of information.
- *Science integration*. These developments in science, in general, approach the Earth as an integrated system and offer an excellent opportunity to include other related sciences, such as social sciences and life sciences.

17.3.2 Actions and Suggestions

The vision requires understanding a conceptual model that is capable of providing a definitive answer, which is reliable and credible. However, building such an integrated view is not straightforward. The development of this view requires resources, and we identified three interdependent sources of resource capital, which need to be improved to achieve this vision:

1. *Technological capital*: Capacity to measure, observe, compute, and store. This requires material, technologies, sensors, satellites, floats; software to integrate and to do analysis and modeling and processing;

building observational, computational, and storage platforms and networks.

2. *Cultural capital*: Open access to data, services, etc., from other research infrastructures. This requires rules, licenses, citation agreements, IPR agreements, technologies for machine–machine interaction, workflows, metadata, data annotations, etc. The goal should be to contribute always to the standard understanding of the systems approach; research infrastructures work together as a community on the policy level.
3. *Human capital*: Specialists to make it all work. This requires both data scientists and discipline scientists. The need of disciplinary specialists is not going away, but answering the societal and environmental challenges needs experts capable of truly inter- and transdisciplinary science, working between the typical scientific boundaries. This also calls for "generalists" who oversee more than just their own discipline. These specialists need their own curriculum and training. Additional human capital need comes from the challenges to include and train citizen scientists.

17.3.2.1 Technological Capital

The environmental science research community has much to gain from the rapid advance of technology in many areas. The research infrastructures in the field are mostly focused on collecting and acquiring observational data, which can be used to gain a comprehensive understanding of the earth system. The technology used for acquiring, storing, and processing environmental research data includes instrumentation such as sensors, floats, radars, and integrated measurement stations, as well as e-infrastructures (in their wide meaning), including networks, computing servers, and storage, together with software components enabling processing of these data. ERIS strategy listed the following key parts of the technology development, with examples of concrete actions:

- *Improved observation systems* (*instruments and platforms*): Enlarging and developing observation coverage, supporting cross-use of experimental research platforms and vessels, scientific gap analysis, station integration between research infrastructures and new observation technologies.
- *Improvements of e-infrastructure*: Establishing fast network connections and data reduction on-site, improving data storage capabilities, developing software solutions for environmental big data applications, common interface development, common API development, and competence center collaboration.

17.3.2.2 Human Capital

To fulfill the need for a systems approach, a complete new type of data specialists is needed, concentrating on producing and maintaining the data products of the research infrastructures. Earth science data specialists have a strong information technology background, but also are well versed in the scientific questions and methodologies of the earth system sciences. They are capable of handling large data sets, understanding the limitations and benefits of different earth system observations and experiments, and are also responsible for the development of e-infrastructure of the research infrastructures. As they are concentrating on the data production and data assimilation, their career paths include far more data publications than other types of publication, and thus their positions are best developed using the data citation services. The career paths of these specialists require completely new positions recognizing their unique services to the science community. Additionally, the need for additional observations and data analysis has brought out the need for citizen science activities. These additional human observers, data scientists, science communicators, and innovators can be a great boon to the research. However, there is much to do to find out how to actually effectively use these resources. Policies on, for example, data integrity, research credit, funding, and trustworthiness are major challenges on using citizen scientists in research infrastructures, and much research and training will be needed in the future if they are to be integrated in the operational research.

The following key developments were identified, with partial associated actions:

- *Curriculum development*: Establishing the career paths for data scientists in the earth system sciences and establishing education and training requirements for data scientists
- *Multidisciplinary training*: Establishing curriculum and programs for cross-disciplinary studies and establishing cross-disciplinary mobility programs
- *Citizen science integration*: Establishing the methodology and practices for citizen scientist interaction with the research infrastructures

17.3.2.3 Cultural Capital

The cultural capital development describes the advances in nonmaterial aspects of the research infrastructures and research landscape. The research infrastructures do not only consist of physical instruments, produced data, or people handling them. A significant—for some cases the main—part of the research infrastructure is the development of methods, policies, and concepts needed for successful research endeavors. Without such developments, the goal of having integrated and complete understanding of the earth system cannot be realistically achieved. The following are the key developments and actions we suggested:

- *Disseminating the idea of a common goal in the earth system sciences*: Publication of the strategy and goals of the European environmental research infrastructures
- *Building the culture of open research*: Requirement of open data access as the standard clause in any public science funding, common and widely used data citation mechanisms and citation indices, taking data publication and citation as a key parameter for merit determination in research infrastructures
- *Standardize the language and terminology*: Harmonization of terminology within the earth system sciences, establishing standards for scientific data including contextualization, and developing and implementation of machine-readable documentation and licensing standards for the earth system data
- *Enlarging the view*: Integration efforts between the earth system communities, and toward including human activities on the earth system analyses and databases
- *Organizational framework*: Establishing coordination structure of environmental research infrastructures, dissemination of the standard model of the planet idea to scientists, funders, and end-user groups.

17.4 Current Activities (as of 2016)

The success and results of the previous ENVRI and COOPEUS (EU) projects motivated the community to continue its collaboration. In the Horizon 2020 program of the EC, two collaboration projects were proposed and successfully funded: ENVRIplus continuing the work of ENVRI and COOP+ similarly building on the COOPEUS activities.

17.4.1 ENVRIplus (2015–2019)

The ENVRIplus (www.envriplus.eu) follows in the footsteps of its predecessor with an aim to enhance the collaboration among the environmental research infrastructures in Europe and to build common synergistic solutions for pressing issues in research infrastructure construction and implementation. However, the ENVRIplus does not go just one, but many steps further. Whereas the main focus of ENVRI was on data and improved software solutions, ENVRIplus has six main objectives, called themes, spreading from the development of common technical solutions, through work on policies for multidisciplinary access to research infrastructures to transfer of knowledge through training activities, etc.

As said before, the overall course of this 4-year project is directly built on the earlier ENVRI experience, but due to the larger infrastructure participation (20 research infrastructures, projects, and networks) and budget (15 million euros), the project is far more ambitious and extensive.

17.4.1.1 ENVRIplus Themes

The ENVRIplus activities are divided to 19 work packages, organized in 6 overreaching activity groups, called "themes." Observant reader will notice many similarities between the ERIS strategy (Section 17.3) and the activities of the ENVRIplus. The themes of the ENVRIplus are as follows:

1. *Technical innovation*, working toward improved research infrastructures' abilities to observe the earth system, particularly through developing and testing new sensor technologies, harmonizing observation methodologies, and developing methods to overcome common problems associated with distributed remote observation networks.
2. *Data for science* will generate common solutions for shared information technology and data-related challenges of the environmental research infrastructures. Especially for challenges related to data and service discovery and use, workflow documentation, data citations methodologies, service virtualization, and user characterization and interaction.
3. *Access to research infrastructures* aims at developing harmonized policies for access (physical and virtual) for the environmental research infrastructures, including access services for multidisciplinary users.
4. *Societal relevance and understanding* will investigate the interactions between research infrastructures and society: find common approaches and methodologies to assess the research infrastructures' ability to answer economical and societal challenges, develop ethics guidelines for research infrastructures, and investigate the possibility to enhance the use of citizen science approaches in research infrastructure products and services.
5. *Knowledge transfer* will ensure the cross-fertilization and knowledge transfer of new technologies, best practices, approaches, and policies of the research infrastructures by generating training material for their personnel to use the new observational, technological, and computational tools and facilitate inter-research infrastructure knowledge transfer via a staff exchange program.

6. *Communication and dissemination* work toward creating research infrastructure communication and cooperation framework to coordinate activities of the research infrastructures toward common strategic development, improved user interaction, and interdisciplinary products and services.

17.4.1.2 Participation Concept

The environmental research infrastructures participating in ENVRIplus are illustrated in Figure 17.2. They represent a major investment from the member states. Even if counting only ENVRIplus research infrastructures in the ESFRI 2010 roadmap (the inner circle of the Figure 17.2), the construction costs are in excess of 1600 million euros, with annual running cost exceeding 300 million euros. The ENVRIplus collaboration and synergies between these research infrastructures thus have a tremendous potential for advantages in terms of added value, return for investment and support for science, and successively also economy and society.

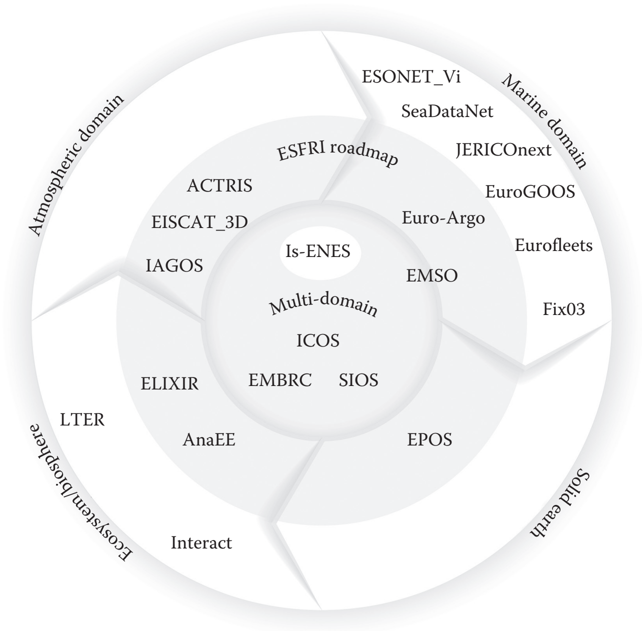

FIGURE 17.2
Research infrastructures from different earth system domains participating in ENVRI and ENVRIplus projects (indicated by symbols). More information about the collaborating infrastructures can be obtained at www.envriplus.eu/wp-content/uploads/2015/08/Booklet_EnvRIs-in-ENVRIplus.pdf.

The ENVRIplus research infrastructures are diverse in institutional aspects and maturity scales. Some of the research infrastructures have already built their facilities and/or are organized as legal entities (e.g., European Research Infrastructure Consortia or associations), some are still developing their logistical and administrative forms and can only be represented by key partners of preparation projects. This heterogeneity in organization creates further challenges for interoperability and is the key background of ENVRIplus: its approach is to integrate as much as possible over this diversity and organize cross-fertilization among research infrastructures. For that reason, ENVRIplus comprises in its partnership not only research infrastructures in the ESFRI roadmap but also research infrastructure projects that have reached sufficient maturity level (outside circle of the Figure 17.2).

The ENVRIplus concept is based on joining the efforts of the research infrastructures in the four environmental domains (atmospheric, marine, ecosystem/biodiversity, and solid Earth domains) to answer the challenges they share. Solutions developed within one domain may also be deployed by research infrastructures in other domains. Developing trans-boundary research requires exploring scientific questions at the intersection of different fields, conducting joint research projects, and developing concepts, devices, and methods that can be used to integrate knowledge. Establishing a cluster of environmental infrastructures is a starting point for reshaping the strategy to conduct research across disciplines.

17.4.1.3 Expected Impact

Impact of ENVRIplus products and solutions is expected on several different levels such as

- *Impact at single research infrastructure level*: The European environmental landscape is fast evolving and new research infrastructure communities are starting their operations. ENVRIplus will support these new research infrastructures and networks to develop and build the necessary structures and services for their users. They can directly adapt and use ENVRIplus services, tools, and products developed in the different work packages. Common modules at research infrastructure level also directly benefits wider communities of multidisciplinary users.
- *Impact on the EU research infrastructure structuration*: One of the main expected impacts of ENVRIplus will be on broadening, supporting, and sustaining the European environmental research infrastructure landscape while reducing the costs of the individual research infrastructure planning, construction, and operations. For example, the take-up of the ENVRI RM at the individual research

infrastructure level will help research infrastructures to adopt common approaches to the whole data management life cycle. This will lead to better interoperability among research infrastructures. Moreover, better interoperability will result in better economies of scale and improved, user-friendly access with greater use of the data and other research infrastructure services.

- *Impact on quality, quantity, and diversity of services offered by research infrastructures*: ENVRIplus improves the innovation capacity of the individual research infrastructures and domains by enabling cross-fertilization of the new knowledge to new solutions and services. An example for that is the implementation of a common data citation system. A single research infrastructure could have a small impact in such general challenge, but the ENVRIplus consortium as a whole may play an important role in cooperation with other projects and initiatives. Limiting duplicated actions and promoting cost-effective solutions for data management, implementing joint guidelines for access, training of staff, etc., will also improve efficiency of research infrastructures, which may revise internally their allocation for services turning them into benefits for users. The level of training in ENVRIplus, together with special outreach to secondary school students will raise educational levels across the European Research Area (ERA).
- *Use of data and data products*: The main barriers for the use (or reuse) of the cross-disciplinary data are not only technology or data issues per se. Several cultural and human-related issues may hinder the use of the cross-disciplinary data. Increased trust and user experience on the research infrastructure data and services is thus another important expected impact of ENVRIplus. Availability of multidimensional data and data products from environmental research infrastructures increases environmental information and brings innovative use of existing information.
- *Building new scientific knowledge*: Multidisciplinary/interdisciplinary research is an important avenue to new scientific breakthroughs. The complex challenges posed by the changing environment will require capacity to address new research concept across different disciplines.

The produced solutions, services, systems, and other project results will be made available to all environmental research infrastructure initiatives in Europe and other places through its Virtual Community Platform (ENVRI VCP, www.envri.eu; to be launched in May 2016). ENVRI Community Platform will be the long-term repository, communication and collaboration tool, and meeting point of all the environmental research infrastructures, projects, and networks. The platform ensures that the ENVRIplus is serving the entire environmental research infrastructure community regardless of their direct participation in the project.

Another key part of the ENVRIplus project, particularly important for the overall infrastructure development in Europe, is the establishment of the Board of European Environmental Research Infrastructures. This crucial component funded by the project is the first concrete step toward creating a strong long-term collaboration, decision-making, and information sharing platform. This board consists of directors or top managers of participating research infrastructures and thus has a strong voice as the representative of the whole environmental research infrastructure community and can act as an intermediary between the research infrastructure user communities (especially, researchers) and the funding agencies as well as international initiatives.

17.4.2 COOP+ (2016–2018)

COOP+ is a partial continuation of the COOPEUS project in the European side. Due to the different context of the Horizon 2020 calls, the scope of the COOP+ is partially smaller (in the context of the earth system domains covered) but in some sense larger (in the context of covered fields and interdisciplinary actions and geographical scope). The general goal of COOP+ is to strengthen the links and coordination of the ESFRI Research Infrastructures related to marine science, Arctic research and biodiversity with international counterparts and to leverage international scientific cooperation and data exchange with non-EU countries (the United States, Canada, Australia, and Brazil) aiming at creating a common ground for the development of a global network of research infrastructures. The project has an ambition to become the central hub for worldwide collaboration of the research infrastructures involved, coordinating all their common activities and fostering international agreements. In particular, the project will

1. Analyze how to address cross-disciplinary global challenges by joining resources including international research infrastructures in the same thematic area. Explore the complementarity of top-down and bottom-up approaches and understand how to combine geographical and temporally explicit scales.
2. Define the basis for an open coordination framework for global cooperation for research infrastructures in the field of environmental science by providing support to new agreements on reciprocal use or access to research infrastructures, openness, joint development of new resources, including cofinancing.
3. Develop and implement a plan for oriented synergistic dissemination and exploitation for research infrastructures at global level.

Identify the different relevant stakeholders, resources, results, and structures in the complex map of environmental research to assure the impact of research infrastructures' products and results. Identify new opportunities for further involvement of research infrastructures and, if possible, of European small- and medium-sized enterprises.

4. Assure the exchange of information and training on best practices and know-how, both for research infrastructure managers and technical personnel and for their user communities, exploiting their complementarity and different experiences.
5. Promote the use of global integrated platforms, in particular, those related to Group on Earth Observation, as a way to accelerate global access to data and address interoperability.

17.5 Conclusions and Outlook

Our planet faces many challenges. To address them for the earth and the society, we need ways to apply science across the traditional national, disciplinary, and earth system domain boundaries. Research infrastructures, as long-term strategic initiatives, play a strong role in generating such integrated and cross-disciplinary science. Current and past activities in Europe have already shown how powerful a tool such collaborations can be.

It is crucial that cooperation will continue in the future. Working just from one (sub)continent is not enough for understanding the global challenges. The collaboration within Europe (ENVRI and ENVRIplus activities) and with major research infrastructures outside Europe (COOPEUS and COOP+ activities) represents a key element in the environmental research development for the next decades.

References

Asmi A., Konijn J. and Pursula A. *ERIS – Environmental Research Infrastructures Strategy for 2030*, ENVRI project publication, available at http://project.envri.eu/, DOI:10.6084/m9.figshare.2067537, 2014.

Chen Y. and Hardisty A. A common reference model for environmental research infrastructures. In the *iLEAPS Newsletter: Special Issue on Environmental Research Infrastructures*, 2014. http://www.neonscience.org/sites/default/files/biblio-files/iLEAPS_Research_Infrastructures_2014.pdf (accessed March 14, 2016).

Chen Y., Martin P. and Magagna B. A common reference model for environmental science research infrastructures. In *the Proceedings of the 27th Conference on Environmental Informatics 2013*, Shaker Verlag, pp. 665–673, 2013.

Donner R., Barbosa S., Kuths, J. et al. Understanding the earth as a complex system—Recent advances in data analysis and modelling in Earth sciences. *European Physics Journal-Special Topics*, 174, 1–9, 2009.

Hermann A., Krige J., Mersits U. and Pestre D. (eds.). *History of CERN: Launching the European Organization for Nuclear Research*, Vol. 1. Amsterdam, the Netherlands: North Holland, 1987.

Houghton J., Townshend J., Dawson K. et al. The GCOS at 20 years: The origin, achievement and future development of the Global Climate Observing System. *Weather*, 67(9), 227–235, 2012.

Koop-Jakobsen K., Loescher H., Powers L., Huber R. and Waldmann Ch. COOPEUS – Building the framework for information exchange between the US and EU Environmental Research Infrastructures. In the *iLEAPS Newsletter: Special Issue on Environmental Research Infrastructures*, 2014. http://www.neonscience.org/sites/default/files/biblio-files/iLEAPS_Research_Infrastructures_2014.pdf (accessed March 14, 2016).

OECD. Global science forum: Establishing large international research infrastructures: Issues and options, 2010. http://www.oecd.org/science/sci-tech/47027330.pdf (accessed March 15, 2016).

Rial J.A., Pielke S.R.A. and Beniston M. Nonlinearities, feedbacks and critical thresholds within the earth's climate system. *Climate Change*, 65, 11–38, 2004.

Steffen W., Tyson P. and Jäger J. Earth system science: An integrated approach. *Environment*, 43(8), 21–27, 2001.