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Comprehensive and Coordinated Approach of GEOSS to Ecosystem Challenges

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Abstract

Terrestrial and marine ecosystems provide essential goods and services to human societies. In the last several decades, however, anthropogenic pressures are causing serious threats to ecosystem integrity, functions, and processes. In turn, ecosystem degradation and loss of ecosystem services can seriously affect human well-being and climate processes on local and regional scales, potentially amplifying the negative effects of global change. Knowledge-based conservation, management, and restoration policies are thus urgently needed in order to ensure the delivery of ecosystem benefits in the face of increasing anthropogenic pressures. The Group on Earth Observations Global Ecosystem Initiative (GEO ECO) uses newly available monitoring methodologies that combine approaches in geosciences and biosciences, remotely sensed data, and in situ observations to provide open-access information on the state and ongoing changes of ecosystems and ecosystem services. The best use is made of existing and future earth observations and field monitoring data, complemented by appropriate interpretation tools and data services, as well as ecosystem models able to use these data. The GEO ECO combines new activities developed in the framework of the European H2020 ECOPOTENTIAL and Satellite-Based Wetland Observation Service projects, with continuing global ecosystem mapping activities carried forward from the former GEO ecosystems task from the first decade of GEO and Global Earth Observation System of Systems (GEOSS), in collaboration with the U.S. Geological Survey, Esri, and a number of international ecosystems experts. In these endeavors, all data, scientific results, models, and information will be made accessible and available through a system of cloud-based open platforms implementing virtual laboratories. Such platforms will be a major contribution to the GEOSS common infrastructure, reinforcing the GEOSS Data Collection of Open Resources for Everyone and in harmony with the Open Data global vision.

Keywords: Global ecosystem monitoring, Ecosystem services and processes, Geosphere–biosphere interactions, Open data

14.1 Introduction

Terrestrial and marine ecosystems provide essential goods and services to human societies (Daily 1997). Over the past decades, however, anthropogenic pressure has caused serious threat to ecosystem integrity, functions, and processes that potentially lead to habitat degradation; creation of uncertainty related to anthropogenically made ecosystems, that is, "novel ecosystems"; and the increased risk of ecosystem collapse (Hobbs et al. 2009, Keith et al. 2013). Ecosystem degradation and loss of services can seriously affect human well-being and economies and potentially amplify the negative effects of global change on local and regional scales (http://www.unep.org/ maweb/en/Framework.aspx).

In addition to scientific discovery, knowledge-based conservation, management, and restoration policies are urgently needed in order to continue to provide and improve ecosystem benefits in the face of these increasing anthropogenic pressures. In order to do this, effective monitoring of the state and trends in ecosystem conditions and services are also needed (MAES 2014, Tallis et al. 2012, Spalding et al. 2013). New monitoring methodologies are now available that combine approaches in geo- and bioscience, remote sensed data, and in situ data (CBD 2014). Till now, however, the use of remote sensing results in the assessment of ecosystem state and changes has been limited by the lack of specific data products that could be easily used for decision-making, that is, natural resource managers, planners, and field personnel (e.g., in natural parks). To achieve maximum benefit from the existing and incoming (new) earth observation (EO) data and other in situ monitoring data, appropriate interpretation tools, data services, and ecosystem models should be developed and used in combination for stakeholders and users outside the research community. Hence, knowledge must come from the codevelopment of data, its information, and data analytics, with the relevant stakeholders to identify the required research outputs and support the use of new data and tools (Stocker 2015). Finally, synergies must be sought among international and European initiatives, projects, and networks, in order to avoid duplication of work and make best use of the available time and funding resources. In the following sections, we address how such challenges are addressed in the framework of the Group on Earth Observations (GEO) and of the large European project "ECOPOTENTIAL." In this project, data, information, and knowledge are managed by applying the DIKW (data, information, knowledge, wisdom) model (Zins 2007), which is about understanding and connecting: information is an added-value product generated by understanding data and working out relations among them and with physical and/or social phenomena, while understanding information and working out valuable patterns generate knowledge.

14.2 GEO View

The GEO was established in 2005 as a voluntary partnership of governments and organizations that envisions "a future wherein decisions and actions for the benefit of humankind are informed by coordinated, comprehensive, and sustained Earth observations and information." To meet this goal, GEO is creating the Global Earth Observation System of Systems (GEOSS) that will link EO resources and data worldwide across multiple societal benefit areas

(SBAs) and make those resources and data available for better informed decision-making and scientific understanding. There were originally nine SBAs: one such SBA was devoted to the global monitoring of ecosystems, and others to agriculture, water, climate, and biodiversity (during 2005–2015). Owing to the scientific and thematic overlap and interactions among the ecosystem and biodiversity SBAs, from 2016 onward, the ecosystem and biodiversity SBAs have been joined into a single biodiversity and ecosystem sustainability SBA. Other changes from the 2005–2015 SBAs are the establishment of disaster resilience, energy and mineral resources management, food security and sustainable agriculture, infrastructure and transportation management, public health surveillance, sustainable urban development, and water resources management SBAs. The choice of these areas emerged from several discussions and meetings between scientists and stakeholders from developed and developing countries that took place in 2015 and identify the most important areas for which data and knowledge access are crucial that the previous group of SBAs did not specifically address. Moreover, partners, particularly those in developing countries, wish to include more practical applications in the SBA structure. In parallel to this general SBA structure, and in order to provide an efficient and sustainable structure for the dissemination of knowledge and results, from 2016, GEO will be organized around a set of community activities, flagships, and initiatives (see www.earthobservations.org), which must be supported by funded projects over a time scale of a few years. GEO community activities intend to codevelop the support system needed for information management, data distribution and sharing; GEO flagships represent an operational stage for the distribution of data and information on a specific issue, while GEO initiatives are activities at a preoperational stage leading to institutional integration and collection of the relevant data and knowledge.

One of such global initiatives is the GEO ECO, the GEO Global Ecosystem Initiative. The goal of this initiative is to collect data, information, and knowledge (including model outputs and model codes themselves) on specific ecosystem types, on their state and ongoing changes, and make them available through the GEOSS system of portals. Special emphasis is given to remote sensing data and products to provide spatially extended information on ecosystems. GEO ECO will work at two different levels: (1) a global mapping of ecosystem characteristics (to be discussed in the following text) and (2) specific information on relevant study sites and ecosystems (usually obtained from protected areas [PAs] where a large body of measurements is often available). In the early stage of development, special focus will be on mountain ecosystems, arid/semiarid environments, wetlands, coastal and marine ecosystems, followed by extensions to other ecosystem types.

14.2.1 Mountain Ecosystems

Mountain ecosystems, rich in endemic and endangered species, are directly linked to downstream regions through ecosystem goods and services, including benefits to watersheds, slope stability, discharge regulation, food and energy production, recreational services and options for tourism. Mountain ecosystems are "sentinels of change" as they are highly sensitive to the impacts of modifications associated with climate and/or land-use change. In addition, pilot sites in mountains integrate a spectrum of altitudinal zones and ecosystems in one PA. The role of mountain regions has been acknowledged at the UN Conference Rio + 20. The spatial heterogeneity of mountains exhibits methodological challenges for EOs (cloudiness, shade, etc.), making these areas excellent training grounds for the development of robust approaches. In Europe, mountainous PAs of international value exist in all climatic zones and latitudes. ECOPOTENTIAL will make use of this "natural experiment."

14.2.2 Arid Ecosystems (Including Semiarid)

Arid ecosystems (including semiarid) exhibit unique pathways of ecosystem function and specialized ecosystem services and represent life under extreme conditions. Such water-limited ecosystems can be vulnerable to the current impacts associated with global change. According to climatic projections, large areas in southern Europe are exposed to the risk of facing significantly drier conditions, and collapse of previous ecosystem functioning can occur as a consequence of increased climatic variability. Here especially, uncertainties are high about future ecosystem behavior. In water-limited ecosystems, temporal variability must in particular be addressed by EO and field data. Hence, we see a strong contribution of these sites to improving the monitoring of temporal dynamics in drylands, a biome that is home to some 2.3 billion people worldwide (http://web.undp.org/).

14.2.3 Coastal/Marine Ecosystems

Coastal/marine ecosystems are "an integrated and essential component of the Earth's ecosystem and are critical to sustaining it" (Rio + 20 outcome document The Future We Want, 2012). Rio + 20 also noted that the health of oceans and marine biodiversity are negatively affected by the impact of human activities, leading to a loss of biodiversity, decreased abundance of species, damage to habitats, and loss of ecological functions and ultimately ecosystem services [14]. Countering these threats is only possible through sustained monitoring and development of indicators to inform policy makers and coastal/marine managers. Coastal areas are transition zones between ecosystems that are of extreme importance for biodiversity and for the exchange, migration, and refuge of species with complex habitat requirements. In consequence, we see this category of ecosystems and pilot sites as a representative for approaches that focus on capturing the mobility of organisms within and between ecosystems.

For such ecosystems, available data and metadata will be collected and made available when possible, models will be developed and implemented, and information will be collected on specific websites, and portals linked with the GEO portals.

The GEO activities are based on voluntary contributions and no direct funding from GEO is available for the initiatives and flagships. Thus, the support should come from externally and independently funded projects. The European Union is supporting GEO through a set of calls that explicitly indicate that the selected projects should be conducted in the framework of—and provide support to—the GEO activities. In 2015, two H2020 projects focused on the use of EOs (both remote sensing and in situ) for the assessment of ecosystem services were selected by the reviewers of the European community and funded (Call SC5-16-2014). The two projects are ECOPOTENTIAL, a large consortium focused on the assessment of mountain environments, drylands, transitional coastal lagoons, and large marine ecosystems (LMEs), which include >25 European and non-European PAs of international relevance, and Satellite-Based Wetland Observation Service (SWOS), a smaller project focused on developing an operational, remote sensing–based, wetland observation service in support of international conventions, regulations, and policy frameworks. ECOPOTENTIAL includes a programmatic emphasis on macrosystems ecology, cross-scale interactions, and coupled geosphere–biosphere processes, and it has the goal of building a GEO Ecosystems Community of Practice, that is, a community of stakeholders that has codeveloped the analytics and best practices, and users trained in the use of the GEOSS system of portals.

In addition to the H2020 activities, global ecosystem mapping work (which began at the inception of GEO and GEOSS) is being carried forward and included in GEO ECO. In partial satisfaction of the former GEO ecosystems activity to "map standardized, robust, and practical global ecosystems for terrestrial, freshwater, and marine environments," a new global terrestrial ecosystems map was produced in collaboration with the U.S. Geological Survey (USGS: Roger Sayre and coworkers), Esri, and a number of international ecosystems experts. This new global ecological land units (ELUs) product is a first-of-its-kind, globally comprehensive, high-resolution, and data-derived characterization (http://rmgsc.cr.usgs.gov./ecosystems/pubs.shtml). While the global terrestrial ecosystems map is now completed, the global marine and global freshwater ecosystem maps are still outstanding. A major collaboration is now underway to produce a first-of-its-kind, 3D global ecological marine unit (EMUs) map in fashion to the ELUs. The global EMUs map will be developed as a short-term (1–2 years) foundational activity of the GEO ECO initiative, and an analog global ecological freshwater unit (EFU) map will be advanced as a longer-term (2–3 years) GEO ECO activity. It is now to the research and user community to get engaged in exploiting such wealth of information, and GEO ECO is ready to help along these lines by organizing training courses and workshops on the use of EO data in ecosystem mapping and characterization.

The scope, timeframe, significance, and resourcing of the two European projects and the two global ecosystem mapping projects (marine and freshwater) are consistent with the nature of the concept and process for developing new GEO initiatives in its second phase of development (2016–2025). Significant H2020 funding for these two European projects and significant in-kind support available for the global ecosystem mapping efforts from Esri are promising indicators of the commitment and likelihood of success for these activities in GEO ECO.

Based on these existing perspectives and results, the GEO ECO initiative intends to build upon available results on a regional or continental scale (e.g., from the ECOPOTENTIAL project) and extend them to a global scale, identifying PAs of international relevance where the same methodology used in ECOPOTENTIAL can be applied. Parallel to this, GEO ECO intends to support the efforts of extending and improving the ELU, EMU, and EFU maps currently in development.

14.3 The European H2020 ECOPOTENTIAL Project

To characterize the current state and the ongoing and expected changes in biodiversity, ecosystem functions, processes, and services, the transdisciplinary European H2020 ECOPOTENTIAL project adopts a blend of EO data and services, in situ monitoring and measurements, and modeling development, including the estimate of cross-scale interactions and future change scenarios (standard IPCC RCP scenarios coupled with available land-use change scenarios).

To tackle the scientific goals of ECOPOTENTIAL and other GEO efforts, we face several challenges:

A first issue concerns the large amount of available ecosystem data (the "Big Data" problem, see Heffernan et al. 2014), from both remote sensing devices and in situ monitoring activities, which should be used and interpreted. Such data come in diverse formats and provide different information and should be harmonized and made available through efficient and easy-to-use platforms that can serve expert users (scientists, technical staff), the stakeholder and policymaker communities, and concerned citizens. ECOPOTENTIAL will develop a suite of data access systems and virtual laboratories for this purpose, building on previous and current projects (e.g., FP7 GEOWOW, H2020 ConnectinGEO) and on the GEO/GEOSS brokering approach (see Section 14.4.4).

A second challenge involves how to address the emerging notions of cross-scale interactions and macrosystem ecology, which explicitly recognizes the presence of multiple and potentially contrasting spatial and temporal scales of ecosystem processes and their drivers. And as such, calls for the need to determine on which scales the information of process rates and their drivers are important to inform other scales, that is, upscaling and downscaling (Heffernan et al. 2014, Soranno and Schimel 2014). ECOPOTENTIAL will develop conceptual approaches to address macrosystem ecology and foster European (and global) research that will provide the context on transfer of information at one scale to different regional to continental scales.

The risk of losing essential ecosystem services and benefits is not just a scientific topic but has profound implications on the society and on economy (MAES Working Group 2014). For this reason, it is essential to develop solid science-policy interfaces to transfer scientific and technological knowledge into citizen information and policy strategies. ECOPOTENTIAL will build upon these needs and construct a system of combined policy options and of capacity building/outreach/dissemination activities at different levels, with the goal of defining and communicating the best strategies and actions for the improvement of ecosystem benefits and the definition of the needs of future PAs.

The ECOPOTENTIAL projects' activities and pilot actions target a set of internationally recognized PAs in Europe, European territories, and beyond; these include mountain, arid and semiarid, and coastal and marine ecosystems (Figure 14.1). These PAs such are chosen because they are exposed to a variety of pressures, which can change their ecosystem state (Marris 2011, Potts et al. 2014, and Chapter 10). ECOPOTENTIAL sites cover most European biogeographical regions and represent UNESCO world natural heritage sites, biosphere reserves, national parks, and important Natura 2000 sites. Additionally, two LMEs in the Mediterranean and the Caribbean are included. Many of the sites considered here exhibit a variety of protection categories. Finally, many PAs are also directly or indirectly linked to European Long-Term Ecological Research (LTER) sites (http://www.lter-europe.net/).

The variety of PAs included in the project, their different protection status, and the spectrum of involved ecosystems and biogeographical regions are a major strength of ECOPOTENTIAL. The project profits from the enormous range of ecological contexts that occur at the European scale and are aiming to create widely applicable knowledge and approaches that can be implemented in the future beyond the specific PAs of this project. It is impossible to realize such an ambition on national scales. This setting allows for addressing questions related to the status and ongoing changes of ecosystem

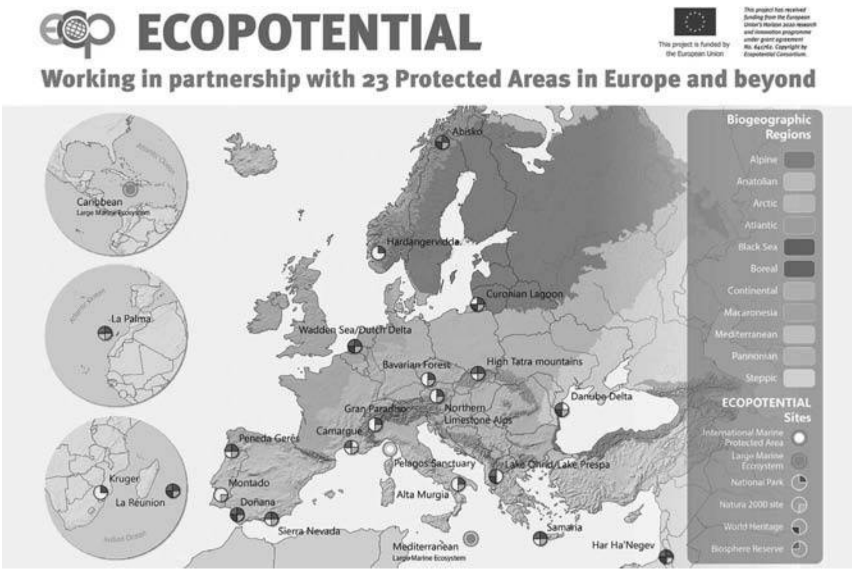

FIGURE 14.1
(**See color insert.**) Location and protection status of the PAs considered in ECOPOTENTIAL and European biogeographic regions.

functions and services in varied environmental conditions and for different protection levels. Based on this, the project will be able to define the needs of future PAs. A major strength of ECOPOTENTIAL is its focus on essential biodiversity variables (EBVs) and other essential variables (EVs) able to synthesize the required information (Pereira et al. 2013).

Building on the knowledge gained in individual PAs, the ECOPOTENTIAL project addresses cross-scale ecological interactions and landscape–ecosystem dynamics on regional to continental scales (Heffernan et al. 2014, Soranno et al. 2014). In this way, ECOPOTENTIAL will provide specific examples of the upscaling of local concepts to pan-European conditions, blending modeling efforts at the scale of individual PAs with large-scale ecosystem and climate models and providing a framework to assess changes in ecosystem services on the continental scale. ECOPOTENTIAL addresses the whole spectrum of ecosystem-related services, by (1) developing ecosystem data services, with special emphasis on Copernicus services, (2) implementing model output services to distribute the results of the modeling activities, and (3) estimating current and future ecosystem services and benefits, combining ecosystem functions (supply) with beneficiaries' needs (demand).

In ECOPOTENTIAL, all data, model results, and acquired knowledge will be made available on common and open platforms, coherent with the

GEOSS data sharing principles and fully interoperable with the GEOSS common infrastructure (GCI). ECOPOTENTIAL will be conducted in the context of the implementation of the Copernicus EO Component and in synergy with the European Space Agency (ESA) Climate Change Initiative. The project activities will contribute to Copernicus and non-Copernicus contexts for ecosystems and will create an Ecosystem Data Service for Copernicus (ECOPERNICUS), a new open-access geospatial data/products retrieval portal and web coverage service using a dedicated online server, which will enable users (from the scientific and management communities) to recover needed information on ecosystem state and changes.

ECOPOTENTIAL is developing strict links with the stakeholder, PA management, and policy-making communities by activating a permanent stakeholder consultancy group and involving PA managers, stakeholders, nature conservation associations, economic sectors, and concerned citizen groups into the definition and discussion of the crucial social and economic needs of local populations. In synthesis, ECOPOTENTIAL addresses the data-to-information-to-decision-making process for ecosystem services, using the interdisciplinary approach of earth system and natural sciences and building on biogeographical developments and the coupled dynamics of climate–landscape–ecosystem processes.

The main reason why the ECOPOTENTIAL project was established is that a large amount of remote sensing (mainly satellite) observations and in situ measurements (here collectively called earth observations) is now available, but till now the use of these data in the development of knowledge-based conservation and management policies has been rather limited. Thus, ECOPOTENTIAL's main goal is to develop a suite of EO products that can help scientists, users, policy makers and stakeholders in the study and management of ecosystems and ecosystem services. To do so, ECOPOTENTIAL opted for focusing its activities mainly in PAs of international relevance, both because these are the "family jewels" of the European environment and host important and endangered ecosystems and because a large quantity of in situ data is available from PAs, thanks to the extensive research activities taking place in those sites.

In summary, ECOPOTENTIAL's most important objectives are as follows:

- Make extensive use of EO data in combination with in situ monitoring. Data from existing archives and new missions (in particular, Sentinel sensors and VENµS) and from ground-based monitoring networks such as those of the LTER Network, the GEO Global Biodiversity Observation Network (GEO BON), the Global Biodiversity Information Facility (GBIF), and the Ocean Biogeographic Information System (OBIS) will be used and integrated to provide a picture of the state and changes in biodiversity, natural capital, and ecosystem services provided by key marine and terrestrial PAs.

- Create an ecosystem data service related to the Copernicus space component (ECOPERNICUS), providing a significant contribution to the research requirement for the Copernicus operational services and allowing simplified access to EO data and products and to ecosystem models' outputs.
- Create a corpus of innovative, field-tested, peer-reviewed, and documented monitoring methodologies to define the ecological status of current and future PAs, based on EO and in situ data.
- Develop a conceptual framework guiding the integration of data, models, and scenarios toward a new vision of ecosystem structure, change, and services. Refine the concept of EBVs, essential ocean variables, and essential climate variables, and define an overarching EV approach in combination with new essential water variables, essential geo variables, and essential social and environmental variables. Link existing and new EVs to EO data and in situ monitoring data.
- Develop new ecosystem models able to make the best use of EO and monitoring data, enhancing our knowledge on ecosystem nonlinearity, complexity, and uncertainties and predicting ecosystem changes in key PAs. The models developed in ECOPOTENTIAL will be able to assimilate EO and monitoring data using a suite of advanced mathematical techniques.
- Address the issues related to cross-scale interactions and landscape–ecosystem dynamics, including biological, geomorphological, climatic, social, and economic connections and emergent properties across scales. Special emphasis is devoted to the propagation of uncertainty across scales, carefully evaluating the different sources of uncertainty and the possibilities to reduce them.
- Quantify ecosystem services, taking into account social demand. Develop a knowledge-based decision support toolbox for management and ecosystem services, based on improved access to PA data and models, and implement an information system to assess the status of terrestrial and marine ecosystem services and resource benefits.
- Develop a list of requirements of future PAs. The scale mismatch between climate models and ecosystem dynamics will be addressed, implementing upscaling and downscaling procedures to obtain a European-wide survey of endangered ecosystems at different spatial and temporal scales.

- Make data, scientific results, models, and information accessible and available through a cloud-based open platform implementing virtual laboratories. This is the ECOPOTENTIAL Virtual Laboratory Platform. The platform will be a major contribution to the GCI, reinforcing the GEOSS Data Collection of Open Resources for Everyone (Data-CORE). By the end of the project, new prototype products and ecosystem services, based on improved access (notably via GEOSS) and long-term storage of ecosystem EO data and information in existing PAs, will be made available.
- Address, through participation of all players in scientific, social, and political decisions, key issues in ecosystem management. A permanent stakeholder consultancy group will be created, which will be kept active after the end of the project creating a GEO Ecosystem Community of Practice. This group will contribute to GEO BON and to GEO Blue Planet and interact with LTER-Europe, the Global Ocean Observing System (GOOS), Biology and Ecosystems (including EuroGOOS and MONGOOS), and OBIS.
- Improve evidence-based environmental policy making, enhancing administrative efficiency and contributing to transparent decision-making. The ECOPOTENTIAL results will directly benefit resource managers and active community stakeholders of selected terrestrial/coastal ecosystems and LMEs. Tested, evidence-based environmental policy making and administrative efficiency will be realized, as well as improved evidence-based environmental policy making and political decisions.
- Develop efficient capacity building at all levels, through training courses and user take-up of EO and monitoring data services and ecosystem models. Citizen science activities in local PA sites will actively involve rangers, wardens, and local citizens in collecting data about natural resources. Development of innovative/interactive outreach tools and dissemination activities will have strong focus on visual components, and networking will be designed in close collaboration with the users.
- Involve small and medium enterprises (SMEs) on EO and monitoring data recovery and services, capacity building, outreach and citizen science, development of virtual laboratories, and apps for the access to geoinformation to ensure commercial uptake and long-term continuation of activities. Involve the expert knowledge of large private companies/foundations/organizations, on ecosystem services and monitoring, fully integrating their contribution.
- Develop a strong European activity within the GEO ecosystem tasks and GEO global initiatives and support/implement the general vision endorsed by GEO/GEOSS.

14.4 GEOSS Information System across Scientific Domains

A central part of GEO's mission is to build the GEOSS information system*: a set of coordinated, independent EO, information, and processing systems that interact and provide access to diverse information for a broad range of users in both public and private sectors. GEOSS links these systems to strengthen the monitoring of the state of the Earth. It facilitates the sharing of environmental data and information collected from the large array of observing systems contributed by countries and organizations within GEO. Furthermore, GEOSS ensures that these data are accessible, of identified quality and provenance, and interoperable to support the development of tools and the delivery of information services. Thus, GEOSS information system increases our understanding of Earth processes and enhances predictive capabilities that underpin sound decision-making: it provides access to data, information, and knowledge to a wide variety of users.

GEOSS information system is intended to support human decision-making and action; therefore, it must be viewed as a work system where humans and machines perform processes and activities using resources to produce specific products and services for customers (i.e., GEOSS Users). In summary, the GEOSS information system is a combination of hardware, software, infrastructure, and expert people organized to facilitate planning, control, coordination, and decision-making in GEO. To build the GEO information system, the GEOSS program applies a "system of systems" (SoS) approach: it consists of developing a central GCI that, proactively, links together existing and planned information and processing systems around the world and supports the need for the development of new systems where gaps currently exist.

14.4.1 GEOSS Information System Community

In the past 10 years, a GEOSS community emerged including four main stakeholders, following a supplier–consumer pattern: (1) information and processing resource providers, (2) GCI component providers, (3) EO application developers, and (4) GEOSS end users (Figure 14.2). The GEOSS information supply system is comprised of the GEOSS resource providers and the GCI providers (i.e., ESA, USGS, CNR, IEEE), while the GEOSS consumers are the GEOSS application developers (e.g., downstream services SMEs) and the GEOSS end users (e.g., data scientists, global changes researchers, teachers, practitioners, decision makers, and citizens).

GEO has devoted considerable efforts to building the GEOSS information system that has made EOs discoverable and in part accessible (see the next

* http://www.earthobservations.org/geoss.php.

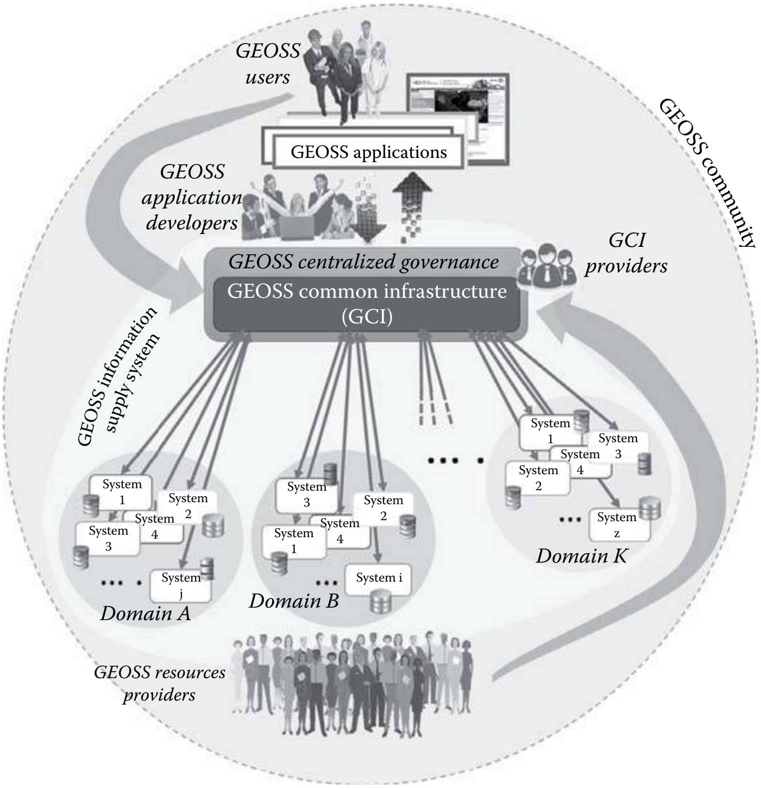

FIGURE 14.2
The GEOSS community.

section on GCI). This information system comprises a large set of resources providers:

Observation (data) systems: These include ground-, air-, water-, and space-based sensors, field surveys, and citizen observatories. GEO works to coordinate the planning, sustainability, and operation of these systems, aiming to maximize their added-value and use.

Information and processing systems: These include hardware and software tools needed for handling, processing, and delivering data from the observation systems to provide information, knowledge, services and products.

To continue leveraging these successes through 2025 and increase EO accessibility and (re)use, GEO will evolve GEOSS and the GCI to meet current and emerging needs by

Extending the user audience to decision makers and the general public

Placing additional focus on the accessibility and usability of EO resources to improve our scientific understanding of the Earth processes and enhance our predictive capabilities that underpin sound decision-making

Providing a service framework to engage partners and user communities in evolving the current infrastructure to enable collaborative tools for cocreation of products and services suitable for effective exploitation by user communities

Evolving the current SoS component-based architecture with an open-systems platform that is flexible, sustainable, and reliable for data access, integration and use, and the delivery of knowledge-based products and services

14.4.2 New GEOSS Information System Strategic Goals and Implementation Plan

GEO is constructing GEOSS based on cycles of 10-year implementation plans—the first plan covered the last 10 years, from 2005 to 2015, while the new period has just started and will end in 2025. Each implementation plan defines a vision statement for GEOSS, its purpose and scope, expected benefits, and a set of targeted "societal benefit areas."

The SBAs recognized by the new GEOSS implementation plan are (GEO 2016) (1) biodiversity and ecosystem sustainability, (2) disaster resilience, (3) energy and mineral resources management, (4) food security and sustainable agriculture, (5) infrastructure and transportation management, (6) public health surveillance, (7) sustainable urban development, and (8) water resources management.

The new plan builds on the following actions:

To implement the "GEOSS data sharing principles": GEO recognizes that the societal benefits arising from EOs can only be fully achieved through the sharing of data, information, knowledge, products, and services. GEO has therefore promoted fundamental principles for data sharing, expanding the trend toward open data worldwide. Thus, as it embarks on its second decade, GEO now aims to implement the following GEOSS data sharing principles:

Data, metadata, and products will be shared as open data by default, by making them available as part of the GEOSS Data-CORE without charge or restrictions on reuse, subject to the conditions of registration and attribution when the data are reused.

Where international instruments, national policies, or legislation preclude the sharing of data as open data, data should be made available with minimal restrictions on use and at no more than the cost of reproduction and distribution.

All shared data, products, and metadata will be made available with minimum time delay.

To implement the "GEOSS data management principles": To further maximize the value and benefits arising from EO data, GEO will continue to work with partners to promote the use of data management principles,* which are based on discoverability, accessibility, usability, preservation, and curation. These principles address the need for common standards and interoperability arrangements. This will ensure that data and information of different origin and type are comparable and compatible, facilitating their integration into models and the development of applications to derive decision support tools.

Stakeholders' engagement: A key tenet of GEO's vision is that EO data should serve societal needs. The value of these data is fully realized when it is transformed into useable knowledge and information to address societal needs. GEO will therefore convene key stakeholders across the provider–user spectrum to codesign a process to systematically identify and document EO needs for addressing specific problems within the scope of the SBAs. Recognized stakeholders include

United Nations agencies, treaties, and conventions

GEO members and participation organizations

Communities of practice

Private sector

GEO engages with stakeholder communities and acts as a broker, connecting users, data providers, engineers, scientists, and other relevant experts to create solutions to global challenges that transcend both national and disciplinary boundaries. Drawing on these partners, which encompass government departments, the private sector, civil society, and academia, GEO will implement a set of core functions essential for the realization of its strategic objectives (GEO 2016). The present strategic plan for implementing GEO considers the following core functions:

Identifying user needs and addressing gaps in the information chain

Sustaining foundational observations and data

Fostering partnerships and mobilizing resources

Advancing GEOSS and best practice in data management and sharing

Implementing sustained global and regional services

Cultivating awareness, building capacity, and promoting innovation

* https://www.earthobservations.org/documents/dswg/201504_data_management_principles_long_final.pdf.

These actions are implemented through four instrument types:

1. *GEO community activities*: They allow stakeholders to cooperate flexibly in a bottom-up fashion and with a low initiation cost.
2. *GEO initiatives*: They allow members and participating organizations to coordinate their actions and contributions toward a common objective within an agreed, yet flexible framework.
3. *GEO flagships*: They allow members and participating organizations with a policy-relevant mandate to spin up a dedicated operational service serving common needs and/or well-defined user groups.
4. *GEO foundational tasks*: They allow GEO to implement selected, often enabling, tasks to achieve the core functions' objectives. For instance, two foundational tasks are devoted to operate and evolve the GCI, while a dedicated task is building the GEOSS knowledge base.

To achieve its strategic objectives, GEOSS needs to be interdisciplinary, drawing on natural, economic, and social sciences and work with stakeholders to answer research questions and communicate recommendations for implementing solutions. Thus, for issues such as climate change, food security, water availability, and ecosystem services sustainability, it is increasingly recognized that we need to develop an integrated multidisciplinary approach to advance our understanding of the complex relationships between environmental and social phenomena (GEO 2009).

14.4.3 GEOSS Interoperability Needs and Implementation Approach

Berners-Lee declared in 2010 "the year open data went global." Since then, hundreds of nations, regions, and cities across the world have launched their own open data initiatives. This open data global movement is characterized by a philosophy and a set of practices of making the data collected by government agencies freely available to the public. Valuable examples are the USGS decision to adopt a policy (begun in 2008) of free and open access to Landsat data and the more recent European Union and ESA commitment to provide open and free access to the Copernicus (i.e., Sentinel satellites) data. In the framework of the Digital Agenda for Europe initiative, the European Union has been working for Open Data portals* to facilitate access to and reuse of public sector information. Open data portals are web-based interfaces designed to make it easier to find reusable information. Like library catalogs, they contain metadata records of datasets published for reuse, that is, mostly relating to information in the form of raw, numerical data and not to textual documents. Analogously,

* http://ec.europa.eu/digital-agenda/open-data-portals.

the Unites States launched the "data.gov"* portal to find data, tools, and resources to conduct research, develop web and mobile applications, and design data visualizations.

The open data global movement creates many opportunities for science to address climate changes' challenges developing an effectively integrated multidisciplinary approach. However, globally shared data need to be harnessed by a new breed of data infrastructures that are based not only on the interoperability of data systems for a specific domain area, but also on the interoperability of multiple disciplines in the physical and social sciences, engineering, and humanities (GEO 2007). For disciplinary and domain applications, systems interoperability largely deals with the adoption of agreed technologies, standards, specifications, and interfaces with a disciplinary/domain services protocol or means of information exchange, if available (GEO 2007). A domain infrastructure requires to be able to address domain resources (or components), achieving interoperability for observations and data models, service interfaces, processing schemes, terms, etc. According to a study of the European Commission (2006), an infrastructure interoperability encompasses at least three overarching and different aspects:

1. Semantics, which ensures that exchanged information is understandable and usable by any application or user involved.
2. Technology, which concerns the technical issues of linking up computer and information systems, the definition of open interfaces, data formats, and protocols.
3. Organization, which deals with modeling organizational processes, aligning information architectures with organizational goals, and helping these processes to cooperate. This category can also include important interoperability challenges, such as data policy, legal, cultural, and people harmonization.

However, multidisciplinary efforts make more complex demands on the type of systems and arrangements needed to support cross-domain activities (GEO 2007). Interconnecting existing disciplinary systems has traditionally introduced limitations to their autonomy and scope. Because different disciplines may have different approaches to data and modeling and different vocabularies (these may be called cultural aspects) and even different interface protocols, bridging across disciplines is a more complex challenge. Thus, interoperability among diverse disciplinary and domain systems must be pursued adopting more flexible and sustainable approaches, the GEOSS brokering approach (see the next paragraph), to introduce such flexibility and evolvability (GEO 2009, 2015). Brokering philosophy is formulated to

* https://www.data.gov./.

handle such differences without limiting the autonomy and without putting a significant investment burden on existing disciplinary systems (Nativi et al. 2012, Vaccari et al. 2012).

14.4.4 Brokering Approach

The notion of "system of systems" (SoS), and the related "system of systems engineering" process, emerged in many fields of applications (De Laurentis 2009) to address the common problem of integrating many independent, autonomous systems, frequently of large dimensions, in order to satisfy a global goal while keeping them autonomous (Karcanias and Essami 2010). SoS can be usefully described as large-scale integrated systems that are heterogeneous and consist of subsystems that are independently operable on their own but are networked together for a common goal (Jamshidi 2005).

The GEOSS mission is to build a global SoS across multiple domains: it is conceived to leverage hundreds of existing and heterogeneous enterprise systems, which belong to different domains and contribute to address the eight SBAs (or great challenges) and the 11 Communities of Practices recognized by GEO, that is, air quality, biodiversity, carbon, coastal zone, cryosphere, energy, forests, geohazards, global agricultural monitoring, health and environment, and water cycle.

In such an ecosystem of domain infrastructures, multidisciplinary interoperability has been traditionally pursued on a one-to-one basis or by asking the stakeholders (i.e., both GEOSS users and resource providers) to be able to utilize the plethora of interoperability standards (both international and community based) characterizing the different disciplinary systems. Clearly, this has represented a high entry barrier for developing cross-disciplinary science and applications (Nativi et al. 2011, 2013). For this reason, a new solution was proposed first by a European FP7 project (Vaccari et al. 2012, Santoro et al. 2010, De Laurentis 2009) and then by a US-NSF initiative (Karcanias and Essami 2010), namely, the brokering approach.

The brokering approach follows these principles to make existing infrastructures and data systems interoperable, in a SoS framework (Nativi et al. 2012):

To keep the existing capacities as autonomous as possible by interconnecting and mediating between standard-based and non-standard-based capacities

To supplement, without supplanting, the individual systems' mandates and governance arrangements

To assure a low entry barrier for both the resource providers and the end users

To be flexible enough so as to accommodate the existing systems as well as future ones

To build in an incremental fashion upon the existing infrastructures (information systems) and incorporate heterogeneous resources by introducing distribution and mediation functionalities

To specify interoperability arrangements focusing on the modularity of interdisciplinary concepts rather than just on the technical interoperability of systems

14.4.5 The GEOSS Common Infrastructure

Realizing a SoS, GEOSS is composed of contributed supply systems, ranging from systems collecting primary data, to systems concerned with the creation and distribution of information products (Nativi et al. 2015). Although all GEOSS systems continue to operate within their own mandates and will evolve, GEOSS systems can leverage each other so that the overall GEOSS becomes much more than the sum of its component systems (GEO 2007). This was achieved by implementing a digital infrastructure that coordinates access to these systems, interconnecting and harmonizing their data, applications, models, and products: the GEOSS common infrastructure (GEO 2007).

Through the GCI, GEOSS resources, including EO data (satellite, airborne, in situ, models), information services, standards, and best practices, can be searched, discovered, and accessed by scientists, policy leaders, decision makers, and those who develop and provide information services across the entire spectrum of users (GEO 2005). The GCI includes three main components: (1) the GEOSS web portal, (2) the GEO discovery and access broker (DAB), and (3) the component and service registry (CSR) (Figure 14.3).

14.4.6 The GEOSS Web Portal

The GEOSS web portal (aka GEOSS portal) offers a single web-based user interface to discover and access the comprehensive data produced by the GEOSS community. A new version of the portal is under development. Developed by the ESA, this new portal is going to make it easier and faster to integrate diverse datasets, identify relevant data and portals of contributing systems, access models and other decision-support tools, and preview data before downloading. The portal is powered by the DAB developed by the National Research Council of Italy (CNR) (GEO 2005).

14.4.6.1 The DAB

Any request received by the GEOSS web portal is forwarded to the DAB, which connects user requests to an ever-increasing number of databases and information systems around the world, that is, the GEOSS resources

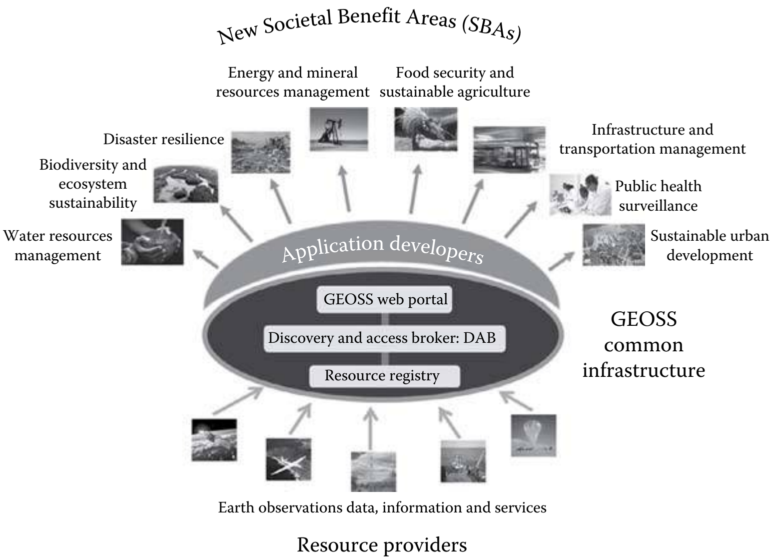

FIGURE 14.3
The GEOSS common infrastructure.

supply system provided by the SoS enterprise systems. DAB applies the brokering principles to interconnect the many enterprise systems constituting GEOSS, that is, the global SoS managed by GEO. Through the DAB services, GCI relaxes the requirement for implementing a common data model and exchange protocol, providing the necessary mediation and transformation functionalities in a transparent way to the SoS components (Nativi et al. 2015). The DAB supports more than 50 well-used and standard protocols, commonly implemented by the GEOSS data and information and service suppliers to share their resources, harmonizing them to provide a unique and consistent response to the GEOSS user requests.

The DAB exposes a set of well-used standard internet interfaces and high-level JavaScript APIs* enabling the developers' stakeholders to implement applications and sophisticated downstream services for the end users. The APIs implement discoverability, accessibility, and simple transformation (i.e., data encoding transformation, coordinate reference systems mapping, data subsetting, and data resolution change) functionalities.

14.4.6.2 The CSR

This tool enables both data and information providers to register their resources and also to share their knowledge and experiences of standard

* http://www.geodab.net/#!apis/ch644.

and interoperability and best practices in all fields of EO (GEO 2005). CSR is developed and managed by USGS.

In the first decade of GEOSS, the GCI has played a crucial role to build the GEOSS information system (see Figure 14.1). The next section will discuss the current contribution of the GCI to the GEOSS information system structure and assets, and the Big Data challenges it had to face.

14.4.7 GCI Contribution to the GEOSS Information System

The main role played by the GCI is to realize the GEOSS information system and noticeably the GCI components' interconnections (Figure 14.3). Presently, more than 145 enterprise systems (spanning from a simple database to complex digital federated infrastructures) are brokered by the GCI. They are the actual GEOSS resource providers and share about 1.3 million of datasets for more than 200 million of discoverable and potentially accessible elements, that is, single files. GEO DAB makes use of the services provided by the CSR and a pool of semantic engines, aligned and managed by the EC-JRC (Joint Research Centre of the European Commission in Ispra). Besides the GEOSS web portal, other (community) portals and applications access the GCI, through the DAB, to discover and access the GEOSS resources.

Recently, GEO decided to engage the private sector considering no-profit bodies (e.g., NGOs) and private companies. GCI has been pursuing interoperability tests with some private systems, in addition to the already public brokered ones (Figure 14.4).

14.4.8 GEOSS Information System and the Big Data Challenges

Big Data topic immediately emerges when considering large and heterogeneous EO systems. The GEOSS information system (and the GCI) goals pose challenges along all the Big Data dimensionalities (Nativi et al. 2015). Each Big Data challenge (commonly known as 'V' axes: volume, variety, velocity, veracity, visualization) required the GEOSS and the GCI to devise and operate ad hoc solutions and strategies (Nativi et al. 2015). This may be considered as the third important GCI evolution, while the second one is the adoption of the brokering approach.

Presently, the GEOSS information system adopts a fully brokering approach implementation, building on cloud computing technology: GCI (i.e., its three main components) moved in the Cloud, realizing a public cloud-based software ecosystem that characterizes the present GEOSS information systems. Community application developers can join this software ecosystem by using the GCI/DAB cloud-based APIs to develop new applications and community-driven portals.

For example, the presently operational DAB configuration takes advantage of the following cloud-specific elements (Nativi et al. 2015):

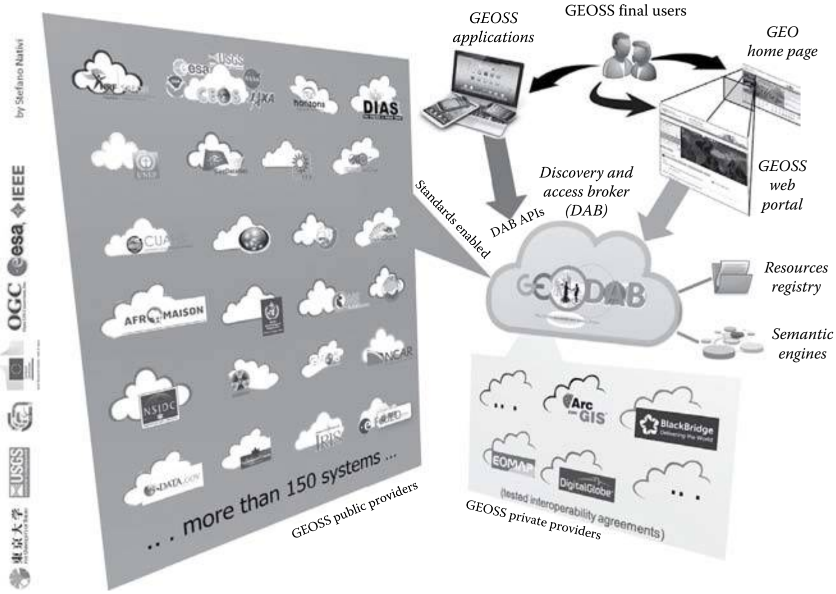

FIGURE 14.4
GCI contribution to the GEOSS information system.

Routing service: This is a Domain Name System service, specifically tailored to be used in cloud environments, that is, the cloud routing service can use cloud-specific functionality to optimize traditional routing functionalities (e.g., route requests to healthy machines).

Load balancer: Provides external client applications with a unique entry point and routes each request to the machine with the lowest workload.

Instance: A virtual machine provisioned by the cloud provider.

Clone instance cluster: A set of instances, every instance in the cluster is assumed to be running the same application with the same configuration (they are clones).

Auto-scaling cluster: An instance cluster that is able to add/remove instances on-the-fly according to a set of scaling rules.

Cluster: A set of instances, every instance can be running different applications with different configurations.

The main solutions and strategies, adopted by the GEOSS information system (and GCI), for addressing Big Data challenges were analyzed by Nativi et al. (2015); in particular, Table 14.1 provides an executive summary of them.

TABLE 14.1

GEOSS Information Systems and GCI Strategies and Solutions to Address Big Data Challenges

Big Data Challenges		**Solutions Adopted to Address the Challenges**
Volume	*Discovery challenges* High number of catalogs, inventory, listing services to be brokered Large number of metadata records Large number of users' discovery requests	Reduce the number of matching results, by supporting advanced constraints in addition to the more traditional "what," "where," and "when." Design and apply a ranking metrics and related paging strategy. Support distributed queries, along with the harvesting approach, to reduce the number of large metadata records to be stored and managed by the DAB. Use of load balancing and auto-scaling clusters to support a large number of queries.
	Access challenges High number of data services to be brokered Large amount of datasets Big data volume Large number of users' access requests	Use of server-side transformation functionalities to limit downloaded data. Supplement missing transformation functionalities (not supported by data servers). Support data caching and map tiling. Use of load balancing and auto-scaling clusters.
Variety	*Discovery challenges* Support of highly heterogeneous metadata models and discovery service interfaces Publication of the set of metadata models and discovery interfaces implemented by GEOSS users' applications Long-term data access sustainability in a multidisciplinary environment	Introduction of a brokering tier dedicated to mediation of service interfaces and metadata models harmonization in a transparent way for both users and data providers. Design and implementation of a brokering semantic and metadata model used. Extensible architecture of brokering to support new service interfaces and metadata models.

(Continued)

TABLE 14.1 (*Continued*)

GEOSS Information Systems and GCI Strategies and Solutions to Address Big Data Challenges

Big Data Challenges		**Solutions Adopted to Address the Challenges**
	Access challenges Support of highly heterogeneous data models, encoding formats, and access service interfaces Publication of the set of data models, encoding format, and access interfaces implemented by GEOSS users' applications Long-term data access sustainability in a multidisciplinary environment	Introduction of a brokering tier dedicated to mediation of access service interfaces and data formats harmonization in a transparent way for both users and data providers. Design and implementation of a brokering data model used to (i) harmonize and integrate the heterogeneous data formats brokered by GEOSS and (ii) expose the data formats well supported by GEOSS users. Extensible architecture of brokering to support new access service interfaces and data formats. Transformations facilitating reuse.
Velocity	*Discovery challenges* To manage the increasing rate at which metadata flows Fast metadata processing to satisfy users' needs	Operational data store that periodically extracts, integrates, and reorganizes brokered metadata records for operational inquire and ranking generation. Caches that provide instant access to the results of distributed queries while buffering data provider systems from additional load and performance degradation. Design of the DAB architecture that balances metadata latencies with GEOSS users' requirements, avoiding assuming that all data must be near real time. Incremental harvesting strategy. Live query distribution combined with caching of results. Load balancing to route incoming requests to machines with the lowest workload. Use of auto-scaling clusters to increase computing capacity in response of rapid workload growth.

(Continued)

TABLE 14.1 (*Continued*)

GEOSS Information Systems and GCI Strategies and Solutions to Address Big Data Challenges

Big Data Challenges		**Solutions Adopted to Address the Challenges**
	Access challenges To manage the increasing rate at which data flows Fast data processing to satisfy users' needs	Operational data store that periodically generates and stores preview tiled maps of brokered data for operational data preview. Caches that provide instant access to the results of previous access requests. Supplementing missing transformations allows limiting the local processing time. For extremely large processing requests, users are allowed to opt for an asynchronous version of the access functionality.
Veracity, value, and validity	*Challenges* Reduction of the "information noise" Retrieved data comparison Data trustiness for GEOSS decision makers Effective data reuse Data meaningfulness for user requests Data accuracy for intended use	The brokering data model includes a specific multidisciplinary quality extension. Implementation of a flexible ranking metrics including quality of service and metadata completeness as valuable indexes. The brokering metadata model supports a harmonized presentation of retrieved metadata facilitating their comparison. Use of GEOSS EVs as an additional parameter for improving the existing ranking metrics. The prototyped "fit-for-purpose" and users' feedback extensions aim to provide users with quality-aware results.
Visualization	*Challenges* Visualization speed Contextualized visualization	Support community portals and applications publishing DAB APIs for client development. Support the following visualization strategy: (1) provide an overview (trying to keep that simple and show important elements), (2) allow zoom and filter unnecessary clutter, and (3) provide more details if requested by users. Provide fast previews by generating preview tiles in batch.

Source: De Laurentis, D., Understanding transportation as a system of systems problem, in *System of Systems Engineering: Innovations for the 21st Century*, 2009, pp. 520–541.

14.5 Conclusions

Ecosystems are rapidly changing worldwide, most of which are a result of the multitude of interacting anthropogenic drivers. The changing ecosystems and the services they provide can seriously affect the benefits to humankind. For these reasons, it is necessary to quantitatively characterize the current state and ongoing changes of ecosystem functions, processes, and services both globally and locally, across the wide range of environments and landscapes that characterize our planet. The logical course of action then lies with developing user-friendly collection, archive, and dissemination of the large amount of heterogeneous EO data from diverse sources. However, a key remaining challenge is converting data to new understandings and knowledge that can be used for ecosystem conservation and management. The GEO ECO initiative, with its supporting activities (i.e., EU H2020 ECOPOTENTIAL and SWOS projects, and partner projects with USGS and ESRI), aims at contributing to this endeavor. In parallel to developing the observational infrastructure, GEO ECO plans to also collect a suite of data models able to incorporate/assimilate EO data to estimate future conditions (states) of selected ecosystems.

Taken in concert, the GEO data infrastructures will assist in developing the new vision of ecosystems as integral, coupled, complex geosphere–biosphere systems where new understandings will be derived to benefit society. All the results, information, and metadata will be made available through a system of portals that contribute to GEO/GEOSS and will provide the structure to derive new knowledge to advance science and improve conservation and management policies.

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Glossary

CBD: Convention for biological diversity
ConnectinGEO: http://www.connectingeo.net/

Copernicus: ESA, http://www.copernicus.eu/
ECOPOTENTIAL: www.ecopotential-project.eu
EFU: Ecological freshwater units
ELU: Ecological land units
EMU: Ecological marine units
EO: Earth observations
Esri: http://www.Esri.com/
FP7: European Union Framework Program 7
GEO: Group on Earth Observations
GEO ECO: GEO Global Ecosystem Initiative
GEOSS: Global Earth Observation System of Systems
GEOWOW: http://www.geowow.eu/
GWOS: Global Wetland Observation System
H2020: EU Horizon 2020 Programme
MAES: Mapping and assessment of ecosystems and their services, http://biodiversity.europa.eu/maes
SBA: Societal benefit area (in GEO)
SWOS: Satellite-Based Wetland Observation Service
USGS: United States Geological Survey

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