Creation and Operation of a Global Earth Observation System of Systems

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Abstract: Integrated global measurements and the information derived from these observations provide critical inputs for sound management decisions on a local national and international scale. For this reason, 72 nations and 44 international organizations have come together to form the Global Earth Observation System of Systems (GEOSS). The purpose of GEOSS is to achieve comprehensive, coordinated and sustained observations of the Earth system to meet the need for timely, quality, long term global information. GEOSS builds on, and adds value to, existing regional, national and international Earth observation systems by coordinating their efforts, addressing critical gaps, supporting their interoperability, sharing information, reaching a common understanding of user requirements and improving delivery of information to users. GEOSS is a complex system of sensors, communication devices, storage systems, computational and other devices used to observe the Earth and gather the data needed for a better understanding of the Earth's processes. In addition, GEOSS includes models and processes to create information from the observational data. This presentation will give the history and details of the current status of GEOSS and its relevance to ocean applications as part of the review of IEEE OES technical committee programs.

I. Introduction

Earth observations are essential for a broad range of daily activities from forecasting and mitigation of natural hazard risks to structuring operational processes and work flows in areas that have environmental constraints or significant societal impacts.

The oceans play an important role in understanding and addressing issues caused by our environment. Thus, the observation of ocean processes on both short and long time scales form an important component of the Global Earth Observation System of Systems (GEOSS). In contrast to meteorology, the establishment of permanent stations in the world oceans that deliver data in real-time or quasi real time is still in its infancy. Only in areas with high economic relevance, particularly along the coastal margins, are observations such as tidal gauge stations routinely maintained. Yet the oceans are recognized for their large impacts on climate, food supply, mineral resources and other factors that support improved quality of life.

This deficiency in blue ocean observations is strongly related to the fact that oceans are an adverse environment. Thus, during the late twentieth century, knowledge of the oceans was gained through forecasting models validated with satellite data that offered the consistent spatial and temporal coverage needed to support timely modeling. This is evolving with the addition of global in situ measurements. There are many examples of the evolution, including the ARGO float program [1] where more than 3000 floats have been deployed and are supplying data at regular intervals, the cabled observatories in Canada, Europe and Japan, the Tsunami Warning System of Asia, or the introduction of longer range gliders. The challenge the ocean community now faces is integrating the disparate observations into a coherent global data set that can be used for both modeling of atmospheric and oceanic dynamics and used directly for real time warnings of significant events. With these successes in mind, the next step has to be creating a broad consensus that both ocean observations and derived data products will justify the effort that has to be spent in creating and sustaining observing systems and data/information products.

Integration of global observations and the translation of such data into information that can be used for more informed decisions is a high priority as stated in the 2002 World Sustainability Summit. In line with this imperative, the mission of GEOSS is to enable and support the truly global perspective of the Earth that is necessary for improving human well-being as nations become more socially and economically integrated. GEOSS will revolutionize the ability to understand and manage the planet. As a global public infrastructure, GEOSS will provide access for a wide range of users to comprehensive, near-real-time environmental data, information and analyses. In doing this, it empowers decision makers to respond more effectively to the many environmental challenges facing modern civilization (Fig. 1). GEOSS is focusing initially on nine societal impact areas: natural and human-induced disasters, human health, energy resources, water, climate variability, weather, ecosystems, sustainable agriculture and monitoring biodiversity (Fig. 2). The oceans play a significant role in many of these societal impact areas.

Ocean science and engineering are crucial to addressing the many significant issues of society today. Improved observations that are both comprehensive and sustainable are necessary to have a complete picture of the globe. While satellite observations address surface characterizations in areas such as temperature, ocean color, "surface height" and salinity, ocean dynamics are driven by the integrated ocean response that extends well below the surface. The need for a comprehensive and accessible characterization as a function of depth in the ocean is clear. GEOSS will be addressing some

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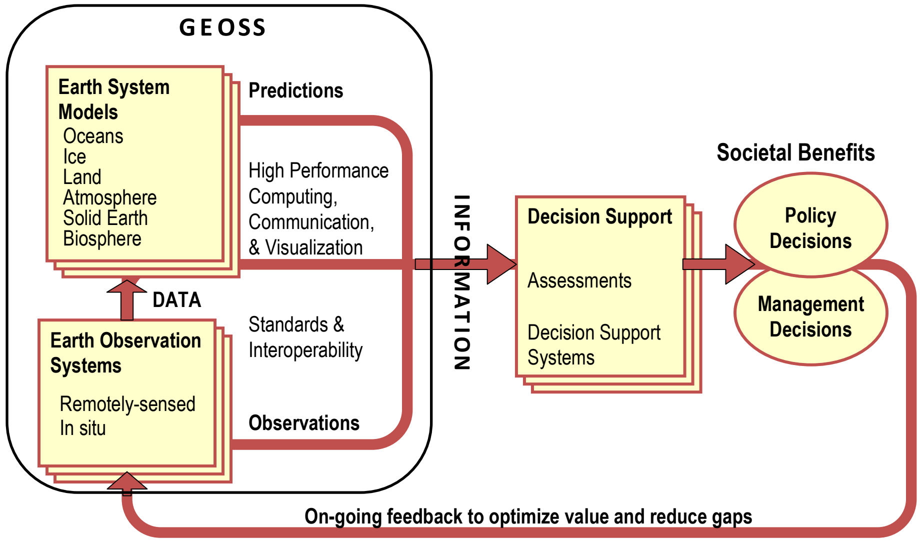

Figure 1. GEOSS Includes both Observation and Modeling to Produce Information for Decisions

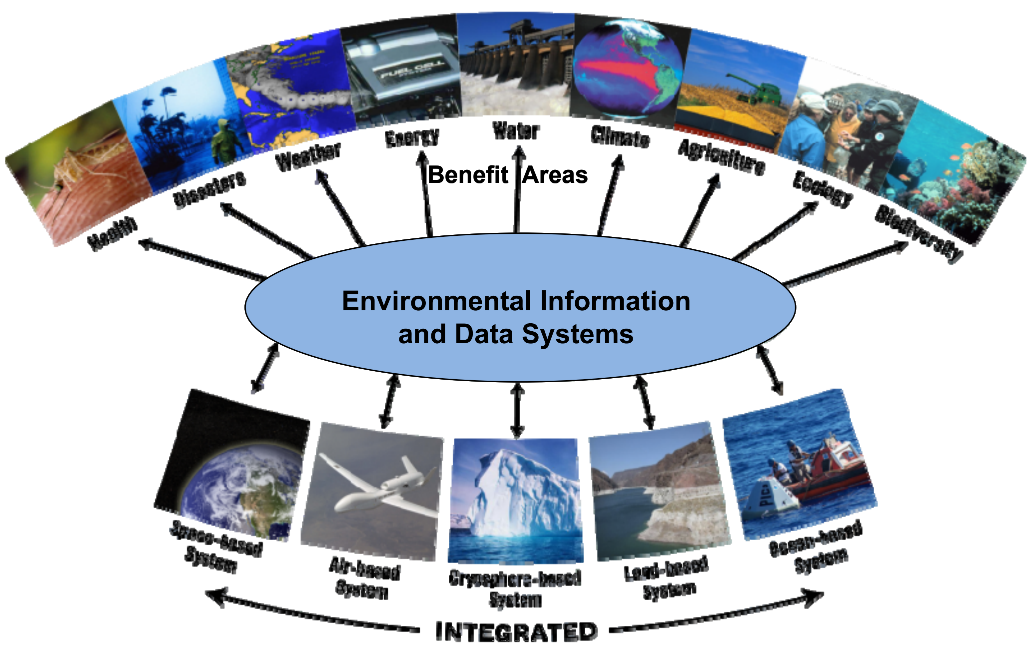

Figure 2. GEOSS Addresses Nine Societal Benefit Areas

facets of this challenge starting in the year 2009. There will be an information framework defined to encourage participation and access to ocean profile data. In addition, the Group on Earth Observation (GEO), the operating organization of GEOSS, will be working to identify critical gaps in ocean observation coverage in conjunction with existing activities to foster investments in these areas. In many cases, this will require improved political visibility of the benefits, both of observations and modeling. With its focus on societal benefits, GEO provides opportunities for such visibility.

The IEEE Oceanic Engineering Society (OES), with its base in science and engineering, can play an important role in the evolution of GEOSS. Priority developments are in observation gap analyses, interoperability among observation systems and among models and, ultimately, in creating a unified picture of the ocean and its interfaces with the atmosphere and the land at its boundaries. While these are challenges for more than one generation, there is a unique opportunity to make progress through GEOSS.

II. GEOSS and Global Observations

2.1 The GEOSS Background

The 2002 World Summit on Sustainable Development [2] focused on the need for creation of a coordinated global observation capability. In particular, it advocated steps to "promote the development and wider use of earth observation [and information] technologies … including, through urgent actions at all levels, to strengthen cooperation and coordination among global observing systems and research programs for integrated global observations, taking into account the sharing of data from ground-based observations, satellite remote sensing and other sources among all countries." Through advocacy from the Group of Eight (G8) leading industrialized countries in Evian, France in 2003, a ministerial summit, the First Earth Observation Summit, was convened in Washington, DC in July 2003 to define and initiate the steps for a Global Earth Observation System of Systems. At the first Earth Observation Summit in Washington, in July 2003, a Declaration was adopted stating the political commitment to move towards development of a comprehensive, coordinated and sustained Earth Observation System of Systems. GEOSS was established in February 2005 by the Third Earth Observation Summit in Brussels with the adoption of a ten-year implementation plan [3].

The Group on Earth Observations (GEO), the organization developing GEOSS, is a voluntary partnership of governments and international organizations. It provides a framework within which these partners can develop new projects and coordinate their strategies and investments. As of January 2008, GEO's membership includes 72 Governments and the European Commission. In addition, 52 intergovernmental, international and regional organizations with a mandate in Earth observation or related issues have been recognized as Participating Organizations. The GEO Plenary meets at least once per year and provides governance for the development of GEOSS. The implementation process is coordinated by a GEO Executive Committee and four committees that address infrastructure, requirements, science / technology and capacity building. Support for the development is provided by the GEO Secretariat based in Geneva. The focus of the ten-year plan is on enhancing societal benefits through improved information and the development of an information framework to support these objectives.

2.2 The GEOSS Common Infrastructure

Interoperability is the key to success of a global information network built upon existing and new observation systems. Thus, it is the mission of GEOSS to provide interoperability between the national and international observing systems and models through the use of standards and common practices. This will allow data from the thousands of different instruments to be combined into coherent data sets. In addition to interoperability, access and sustainability are keys to utility. The GEOSS Common Infrastructure (CGI) was implemented to support both the observation community and end users of environmental information. The GCI is shown in Fig. 3.

A GEOPortal offers access for GEOSS users seeking data, imagery and analytical software packages (Fig. 3). Other key elements of the GEOSS architecture include the means of discovering data (the clearinghouse), a registry system for components and services, a standards registry for interoperability arrangements and a wiki for collecting and propagating the use of common practices in earth observation and information. GEOSS is not a large archive with search storage and distribution. It is a distributed system of systems with access and discovery, and draws on existing archives for their data storage. Services and data sets are registered with GEOSS, and in doing so, agree to comply with GEOSS interoperability standards. While users can access GEOSS participating systems directly, in doing so, they may not benefit from interoperability features provided by GEOSS.

Commonly used standards in Earth information systems are registered in the GEOSS standards registry. In the case where systems employ operating agreements that have not been through the formal standards development process, GEOSS has a special arrangements registry. This is an area that is evolving. To facilitate interoperability, GEO has created a Standards and Interoperability Forum (SIF) to work with users on special arrangements and define gaps in formal standards.

Where commonality of practices are needed to stimulate interoperability of data, GEO has created a wiki form of registry. The wiki encourages peer reviews of practices and leads to convergence of measurement methods. The challenge of standards and best practices in ocean observation is an important area that can be nurtured through the international cooperation that GEOSS facilitates.

2.3 Key Technologies for Global Observations

2.3.1 Historical Aspects of Global Ocean Observation Systems

Starting out with the first expeditions 150 years ago, the global observation of ocean processes has been a long lasting endeavor. It can be judged as a natural approach that these

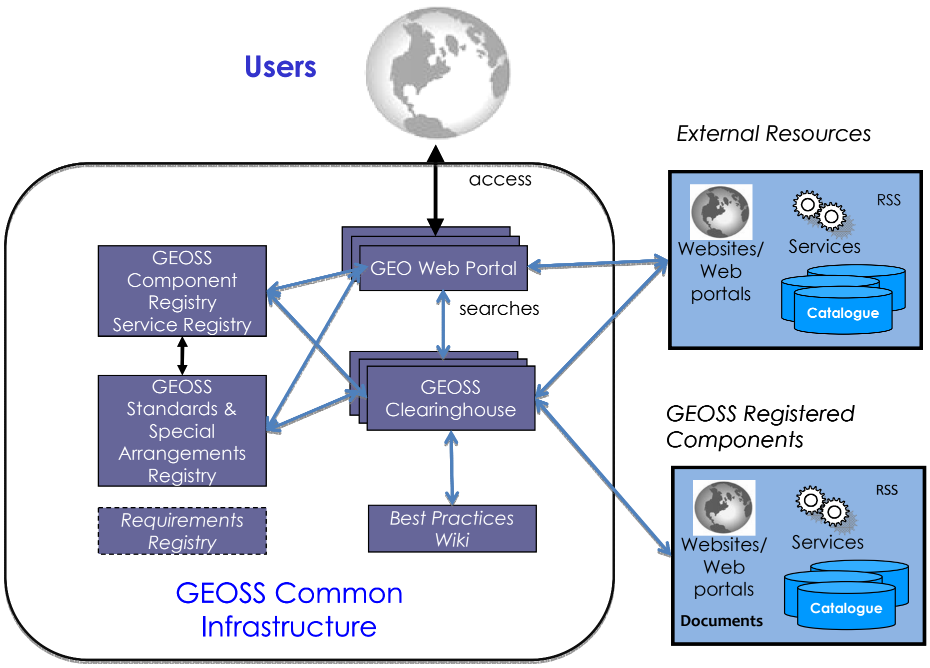

Figure 3. GEOSS Core Architecture

first expeditions were focusing on large spatial structures in the oceans assuming also that temporal rates of change in particular in the deep sea is low. As a result, maps of physical properties have been developed and actually served as a reference for decades [4]. Starting in the 1980's, new insights were gained through different large scale observation programs such as the Mid-Ocean Dynamics Experiment (MODE) and the Polygon Mid-Ocean Dynamics Experiment (POLYMODE); the result of these developments showed that most of the energy in the ocean is stored in mesoscale processes [5]. The appreciation of the importance of high temporal resolution ocean observations and a synoptic sampling strategy resulted from this finding. Remote sensing brings the scientific community close to this ideal. However, due to physical constraints, satellites are only scratching the surface of the water body.

To achieve a comprehensive picture it is necessary to build up infrastructures that can contribute by providing in situ observations through the water column. With the advent of the Tropical Ocean Global Atmosphere (TOGA) [6] program and the World Ocean Circulation Experiment (WOCE), both started in the 1980's, the founding initiative of a new generation of global ocean observation programs has been put into place. From TOGA, the Tropical Atmosphere Ocean (TAO) [7] developed which consists of 70 buoys deployed along the equator in the Pacific Ocean. With the data being transmitted in real-time, an improved El Nino forecasting system has been installed.

Although the WOCE program has had a limited life, it provided the basis for different follow-up programs and also delivered the necessary arguments for putting the Global Ocean Observation System (GOOS) initiative on track. Interestingly enough, WOCE was the first program where quality standards for measurements were brought up [8, 9]. In particular, in physical oceanography all scientists involved in the program were confronted with the so called "WOCE standard" for conductivity, temperature, and depth (CTD) measurements which described the requirements of the specification as well as the calibration procedures and the proper processing of the collected data.

2.3.2 Lessons Learned from TAO and WOCE Observation Programs

Both the TAO and the WOCE programs serve as good templates for the installation of future observational programs. Within TAO, the in situ ocean component was essential in predicting the occurrence and intensity of the coupled atmospheric/ocean process under investigation. With the different observational components including satellite atmospheric and in situ ocean data, a powerful forecasting system has been put into place which describes a phenomenon with a global impact. In this context the need for this type of infrastructure is obvious.

WOCE had as a clearly defined objective the improvement of existing ocean models for basin scale processes. This could only be achieved as a truly international effort due to the amount of ship time and data analysis effort needed. Having different groups involved, a quality standard for the measurements had to be developed. It was not a complete quality management system but it certainly introduced this topic into ocean sciences for the first time. WOCE also integrated different observational platforms like ships, satellites and autonomous floats that were similar to those that are currently used in the ARGO program. From this evolved the multidisciplinary aspects where different disciplines benefit from each other. This became an important prerequisite for the justification of future ocean observatory systems.

It must be said that ocean processes and the interaction with the atmosphere have a significant complexity which makes any kind of forecasting very difficult. As long as the oceans stay as under sampled as they are now, it will be difficult to expect major progress in regard to more reliable, predictive models.

2.3.3 Open Ocean and Coastal Observations

The infrastructure that is currently available for in situ ocean observations have to be separated into a coastal part and an open ocean part for technical reasons. The deployment and servicing of coastal systems are much easier and therefore a sustained operation can be achieved. Also there is the immediate interest in the coastal seas as a significant part of the world population is living close to shore and time frames for impacts (such as from pollution events) are short. As mentioned earlier, tide gauges, together with buoys with CTD and current meters, are forming the backbone of most observation programs of national hydrographic offices.

For the open ocean, new strategies had to be invented to support scientific requirements. The ARGO program is one of the successful implementations of an adapted measurement strategy. It currently consists of more than 3000 float systems that continuously deliver CTD profiles and current data from all over the world oceans. Information about the ARGO data capture and archiving systems can be found on the Internet [10].

Other technical developments that are currently being tested hold similar promises in regard to ocean observations. For instance, gliders, briefly described as autonomous floats with wings, will surely contribute to observations covering regions of limited extent. They are close to becoming an operational tool as moorings or current float systems [11].

Cabled observation systems are currently being built in Canada and Japan. Similar initiatives in the USA (OOI) [12] and Europe (ESONET) [13] are underway but have not received adequate funding yet. From a technical point of view, cabled observatories are the highly challenging although they finally will deliver the most sustained information in regard to scientific and technical data in focused regions.

2.4 Coastal and Ocean Numerical Modeling

It is very difficult to describe the dynamics of the coastal zones and oceans from measurements alone. Satellites can observe some processes almost everywhere every few days. But they observe only some processes, and only near or at the surface. Ships can measure more variables, and probe deeper into the water, but the measurements are sparse. Hence, numerical models still provide the only useful, global view of ocean currents. Numerical models of ocean currents have many advantages. They simulate flows in realistic ocean basins with a realistic sea floor. They include the influence of viscosity and non-linear dynamics. And they can calculate possible future flows in the ocean. Perhaps, most importantly, they interpolate between sparse observations of the ocean produced by ships, drifters, and satellites. Four types of numerical models are used: (a) global, (b) coastal, (c) assimilation, and (d) coupled oceanic-atmospheric models.

For global applications, one of several important global numerical models is the Geophysical Fluid Dynamics Laboratory (GFDL) Modular Ocean Model (MOM), developed at Princeton University in the USA [14, 15]. This is perhaps the most widely used model growing out of the original simulation model developed by Kirk Bryan and Michael Cox in 1969 at GFDL. The GFDL MOM consists of a large set of modules that can be configured to run on many different computers to model many different aspects of the circulation. The model is widely used for climate studies and for studying the ocean's circulation over a wide range of space and time scales.

For coastal zone applications, many different coastal numerical models exist for describing coastal currents, tides, and storm surges. These models extend from the beach to the continental slope, and they can include a free surface, realistic coasts and bottom features, river runoff, and atmospheric forcing. Because the models don't extend very far into deep water, they need additional information about deep-water currents or conditions at the shelf break. The many different coastal models have many different goals, and many different implementations. Several excellent listings of atmospheric and oceanic circulation modeling projects can be found on the Internet [16].

Few models have output, such as current velocity or surface topography, which are constrained by oceanic observations. Thus, how can satellite and drifter data be included in models to produce a more exact representation of the ocean? For example, how can we include satellite altimetry measurements of the sea-surface topography and WOCE measurements of currents and internal density in the ocean to make a better model of the present ocean currents? Models which accept data that they are also trying to calculate are called "assimilation" models.

Because of the complexity in addressing all of these factors, modeling of the ocean has been, until recently, addressing only part of the issues in any one model. This is changing, as the ocean modelers have striven to model the full three-dimensional structure of the ocean and capture the full nature of the currents and the deep circulation. Presently, full three-dimensional ocean models utilize momentum, atmospheric moisture and energy coupling, and full three-dimensional heat transport interactions in the water column. Ultimately, this has allowed modelers to use the coupling of ocean – atmospheric models to predict long term trends in climate modeling. Far from being a supplement to atmospheric models, ocean models are now becoming a very critical component in coupled climate system models.

Finally, coupled oceanic-atmospheric numerical models are used to study the climate system, its natural variability, and its response to external forcing. The most important use of these models has been to study how Earth's climate might respond to a doubling of CO2 in the atmosphere. Much of the literature on climate change is based on studies using such models. Other important uses of coupled models include studies of El Nino and the meridional overturning circulation. The former varies over periods of a few years; the latter varies over a period of a few centuries [17]. Further reading on the use of ocean modeling with global ocean observing systems can be found in an excellent article by Smith [18].

2.5 Global Observations and Impacts

What is the impact of global ocean observations? First, they enable better use of existing data sources. Because of the importance of ocean data, some individual nations have rather restrictive data policies. This not only hinders progress in forecasting capabilities, but may in some cases have severe consequences for neighboring countries in regards to managing environmental disasters.

The main benefit from global ocean observations will come not just through the data themselves, but through appropriate assimilation strategies and improved models. As an example, the scientific objective of ARGO is to come up with reliable data on the heat storage in the world oceans and through this, help to detect and quantify climate change and possible impacts on other processes like ocean currents. Questions like whether a detected change is part of a trend that might lead to a major change in the ocean circulation, or due to natural variability that will reverse in the future shall be addressed with the ARGO array.

Investigation of the coupling of processes on a large scale will be another important issue that will be possible to investigate. This will have influence on, for instance, fisheries where observed trends can be used to forecast fish stocks and help to define fishing rules to help preserve natural resources.

In regard to climate change, it will be important to better understand the impact of certain events like increased calving of ice sheets on the overall system and to find out about possible feedback mechanisms. This can only be done on a global scale as regional effects may cover global trends.

Due to the current lack of knowledge in regard to the role of the world oceans in the climate system, and the growing concern within the society about possible severe consequences of climate change, the need for adequate ocean sampling is obvious. Therefore, the integration of existing ocean observation capabilities into GEOSS and the establishment of additional capabilities become necessary [19].

III. GEOSS INTEROPERABILITY AND BENEFITS

In the implementation of GEOSS, increased sharing of methods for modeling and analysis needed to transform data into useful products is a priority. In building an infrastructure and addressing gaps in observations, GEO first must elucidate user needs across the various societal benefit areas. These requirements include specifics such as location, frequency, and accuracy for data sets. GEO can also provide a framework for securing the future continuity of necessary observations and initiating new observations. GEO could act as a forum for discussion on common implementation issues at regional and trans-national levels, such as transportation of in situ observation devices across borders.

With the requirements defined, the major challenge of GEOSS is developing comprehensive and sustained observations and information. This, interested countries and organizations have collaborated to develop and adopt a 10-Year Implementation Plan to ensure the quality of Earth observations over a long duration. This plan builds on, and adds value to, existing Earth observation systems by coordinating their efforts, addressing critical gaps, supporting their interoperability, sharing information, reaching a common understanding of user requirements and improving delivery of information to users. For information needs common to the nine focus societal benefit areas, GEOSS will facilitate the development and provision of common products such as maps of topography, bathymetry, river systems, infrastructure, and land cover and land use, and a geodetic reference frame for Earth observation. Interpretation and use of Earth observations requires information on drivers and consequences of change, including geo-referenced socio-economic data and indicators.

To support these objectives and requirements, GEOSS, supports several functional components which:

- address identified common user requirements
- acquire observational data
- process data into useful products
- exchange, disseminate, and archive shared data, metadata, and products, and,
- monitor performance against the defined requirements and intended benefits.

To facilitate this functionality, GEO employs a range of methods which include: establishment of standing and specific task-oriented GEOSS structures; referring specific tasks to participating international organizations or agencies; coordinating and cooperating with national agencies; collaboration between international organizations; providing a forum for dialogue and resolution of issues at varying levels from ministerial and senior official levels to scientific and technical levels; and advocacy within and across existing systems and other mechanisms.

3.1 Architecture and Interoperability

As mentioned earlier, the success of GEOSS will depend on data and information providers accepting and implementing a set of interoperability arrangements, including technical specifications for collecting, processing, storing, and disseminating shared data, metadata, and products. GEOSS interoperability is based on non-proprietary standards, with preference to formal international standards. Interoperability will be focused on interfaces, defining only how system components interface with each other and thereby minimizing any impact on affected systems other than where such affected systems have interfaces to the shared architecture. For those observations and products contributed and shared, GEOSS implementation will facilitate their recording and storage in clearly defined formats, with metadata and quality indications to enable search, retrieval, and archiving as accessible data sets.

To help in the process of reaching consensus on GEOSS interoperability arrangements, the GEO Architecture and Data Committee (ADC) established the Standards and Interoperability Forum (SIF). The SIF [20] helps GEO organizations offering components and services to GEOSS understand how to work with the GEOSS interoperability guidelines and how to enter their "interoperability arrangements" (standards or other ad hoc arrangements for interoperability) into the GEOSS registries.

In addressing diverse societal needs, an activity may require the exchange of data and information between disparate disciplines that do not traditionally interact and therefore lack established common standards necessary for interoperability. For this reason, GEOSS interoperability arrangements must include a process for bridging these gaps and, if necessary for initiating the creation of new standards where the need arises. The SIF exists to facilitate the interchange of information, and make recommendations for standards and interoperability in GEOSS.

Although GEO encourages the use of open international standards, GEOSS must also accommodate the use of non-standard practices. Thus, the GEOSS Standards Registry contains information on these non-standard practices or interoperability "special arrangements." The process for entering special arrangements into the Standards Registry is handled by the SIF.

The SIF is composed of experts nominated by GEO Members and Participating Organizations. The SIF also draws on subject matter experts who possess an understanding of the protocols, standard arrangements and other technological practices specific to a particular domain of knowledge, community of practice or other endeavors in support of the GEOSS designated Societal Benefit Areas. The SIF works by consensus of its participants.

The SIF is enabling ever greater degrees of interoperability among GEOSS components through facilitation, technical analysis, advocacy and education [21].

3.2 Data Sharing

The societal benefits of Earth observations cannot be achieved without improved data sharing. Data policies vary widely across the globe. To provide a more uniform approach, the following data sharing principles are part of the GEOSS plan:

- There will be full and open exchange of data, metadata, and products shared within GEOSS, recognizing relevant international instruments and national policies and legislation.
- All shared data, metadata, and products will be made available with minimum time delay and at minimum cost.
- All shared data, metadata, and products free of charge or no more than cost of reproduction will be encouraged for research and education.

IV. IEEE ROLES AND CONTRIBUTIONS

With the challenges of creating a global understanding of the Earth environment stemming from the complex nonlinear coupled processes, the benefits of a global earth observation system cannot be understated. As indicated earlier, GEO is constructing GEOSS on the basis of a 10-Year Implementation Plan for the period 2005 to 2015. To achieve the goal of developing a comprehensive and sustained GEOSS, there is a need for key technologies that can build and support information and decision making infrastructure on levels ranging from global to local. These technologies - in communications, information processing, and environmental measurements - span the IEEE's portfolio of technical expertise and form the technical basis for creating and sustaining GEOSS. There is also a need for education, outreach and planning for applications to ensure the realization of the intended societal benefits.

The IEEE Committee on Earth Observation (ICEO) supports the GEO Vision for GEOSS: to realize a future wherein decisions and actions for the benefit of humankind are informed via coordinated, comprehensive and sustained Earth observations and information. The ICEO, established in 2003, provides a focal point for IEEE support of GEO. Through its participation in GEO, the IEEE is playing an important part in addressing some of the global Grand Challenges.

Through GEO, the IEEE will promote the roles of its members in electro- and information technologies and associated Earth and environmental sciences to the broad global community of Earth information providers and users. The means for promoting Earth observation technology and its benefits includes IEEE-sponsored conferences, workshops, and publications. This initiative thus provides a key means by which IEEE can reach out to a large segment of the global public who are users of the electrotechnology that is the result of IEEE members' inventiveness.

The ICEO Standards activities support interoperability, a key to the success of GEOSS. The IEEE Standards Association and the ICEO have created the Earth Observations Standards Coordinating Committee (SSC40) and the Committee on Earth Observations Standards Working Group. The Earth Observations Standards Coordinating Committee (SCC40) oversees the development of standards that are essential to the functioning of GEOSS. This includes standards related to sensor systems, telemetry and other networked communications, data processing, data archiving and cataloging, data searching and access, data portrayal, and decision support systems.

The IEEE Committee on Earth Observations (ICEO) Standards Working Group (ISWG) and the GEO Standards and Interoperability Forum (GEO SIF) interface with the GEO Architecture and Data Committee, which oversees all architecture and data management aspects of the design, coordination, and implementation of GEOSS. The ISWG is primarily responsible for maintaining the Standards Registry. Other tasks include (a) the standards taxonomy, (b) the Earth observation portal study, (c) the maintenance of list and contact information for Standards Development Organizations (SDOs), and (d) support for the SIF and SCC [22].

V. Plans for GEOSS and OES in Ocean Applications

In recognition of the impact of the ocean on many of the societal issues, the development of a comprehensive ocean monitoring and modeling capability is essential in the development of GEOSS. This can be done in a number of stages leveraging the existing and planned satellite and in situ observation systems. The first stage is development of a framework for facilitating information access and ease of use. Steps in this direction have been initiated through Global Ocean Data Assimilation Experiment (GODAE) and other programs and continue to be facilitated by GEO. For this first stage, GEOSS has created the Interoperability Registries, the SIF and the Best Practices WIKI. In addition, in 2009-10, GEO will work with the existing deep ocean and coastal data programs to provide a common information infrastructure for improved global access. This will offer significant benefits as new measurement techniques evolve and high speed internet plays an increasing role in ocean observations.

Looking beyond observation, GEO is initiating an activity in stimulating web-based interactive models. In its simplest form, this will provide opportunities for sharing models. However, the long term objective is to allow models from multiple domains and specialties to “collaborate” in developing outcomes for complex, non-linear environments. This offers many challenges, the first of which is to define the scope of the possible, both with our current computational resources and envisioned future capabilities. In these next steps, the ocean community can play an important role in both defining future directions and creating the tools to better understand the Earth and its environment.

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[22] S. F. Browdy, GEOSS Overview and the Standards Process, Presentation to the IOOS DMAC, May 2008.

Several additional sources of information about GEOSS, including the following:

The Group on Earth Observations (or GEO) site: http://earthobservations.org

The IEEE Committee on Earth Observation (ICEO) site: http://www.ieee-earth.org

The IEEE Oceanic Engineering Society site: http://www.oceanicengineering.org/index.cfm

The IEEE Oceanic Engineering Society site: http://www.oceanicengineering.org/index.cfm

The IEEE Geoscience and Remote Sensing Society site: http://www.grss-ieee.org

The ICEO Earthzine site: http://www.ieee-earth.org/ default.taf?menu=publications&feature=earthzine&title=Earthzine

An article in Earthzine Journal: http://www.earthzine.org, entitled "The GEO Challenge: An Earthzine Conversation with GEO Secretariat Director José Achache"

GEO document entitled "The First 100 Steps to GEOSS" at: http://earthobservations. org/documents/the_first_100_steps_to_geoss.pdf