The following Report of the GEO Subgroup on Architecture is composed of seven sections that collectively satisfy the request made by the ad hoc intergovernmental Group on Earth Observations. The sections are: Needs, Approach, Principles, Components, Interoperability, an Expanded Functional and Behavioral View of GEOSS and a Functional/Behavioral Model Application to GEOSS Variants.

2.1 Needs

As envisioned, GEOSS will be a system of systems wherein existing individual components across the processing cycle from data collection to information production maintain their responsibilities including technical operations, and national, regional and/or intergovernmental ownership within their mandates. For required new components, GEOSS participants will establish, or encourage their establishment as appropriate, or find an existing organizational entity to assume the new responsibility. The GEOSS architecture describes how components fit together to produce an overall system capable of providing data and information that will better satisfy requirements than the individual components or systems of which it is composed. User requirements are described in the User Requirements report and processes that use observations to satisfy those requirements are described in the Data Utilization report, including a delineation of key parameters among the various Earth disciplines.

The purpose of diagram Figure 2.1 is to visualize processes within GEOSS and to illustrate how societal benefits come from comprehensive, coordinated, and sustained Earth observations.

Figure 2.1 Societal Benefits from Earth Observations
The architected components of GEOSS will be derived from required strategies and systems for Earth observations. The GEOSS architecture will link together those strategies and systems to facilitate Earth observations in a comprehensive, coordinated, and sustained manner. A comprehensive GEOSS architecture will meet the requirements of a wide variety of decision makers and applications worldwide and will encompass in situ, mobile, airborne and remotely-sensed observations from future, current, and predecessor systems. A coordinated GEOSS architecture will leverage existing standards, policies, and programs worldwide. A sustainable GEOSS architecture will address the need for continued, long-term financial and in-kind support for the priority programs of GEOSS, including relevant, agreed-upon research and development.

2.2 Approach

The list of societal issues and political benefits to be derived from GEOSS, as well as the generic GEOSS architecture described in this section, provide an excellent foundation upon which to carry forward the work towards its implementation. However, to define an actual and credible GEOSS architecture that can be progressively built up during the 10-year implementation period, it is essential to know what systems may comprise the system of systems. This vital input, together with other important information, will allow the description of a realistic initial GEOSS architecture. Such input will also contribute significantly to identifying the gaps in the infrastructure required to measure the key parameters needed to address the societal issues and political benefits identified in the User Requirements report. Accordingly, work will begin on the inventory of systems, including current, planned, and future possible GEOSS components. In anticipation of a more formal approach, member governments and organizations may wish to make a start on identifying candidate systems for which they are responsible.

The GEOSS architecture will be defined based upon products needed to meet national, regional and global objectives, and the data and information required to provide these products. The process for assessing the current architecture and defining the proposed future architecture should include an evaluation of how existing products could be improved as well as the need for new products. This will lead to the identification of observational gaps and overlaps, which are matters of concern in the areas of user requirements and data utilization as well as in the architecture itself. Compatibility between observations made by different observing components is also essential. Adherence to the best practices for accuracy and continuity of data records will be a fundamental aspect of the architecture. Development of GEOSS should include the assessment of current investment planning methods and should build upon best practices, with the goal of moving towards common approaches that facilitate identification of shared benefits and interests.

The approach should also build upon what already exists, both in terms of existing systems and historical data sets, as well as existing documentation describing observational needs in various domains. An implementation plan for the next 10 years will be required to establish GEOSS, bearing in mind cost effectiveness, technical feasibility and institutional feasibility, and giving priority to issues of importance and requiring urgent actions for mankind. GEOSS will need to be sustained over a long period of time, with suitable spatial and temporal resolution. Such a system should be adjustable, flexible, adaptable, responsive to future changing needs, and include monitoring and evaluation for continuous improvement.

2.3 Principles

The ultimate goal of GEOSS is to collect information and data contributing to the purpose of GEOSS — to provide useful data and knowledge to achieve better understanding, assessment and prediction of the entire Earth system and to support sound decision-making processes and contribute to socio-economic
well-being. Through these efforts, GEOSS supports sustainable development for all mankind. The following principles will guide GEOSS establishment, implementation and sustained operations.

2.3.1 Characteristics - GEOSS should be a comprehensive, coordinated, and sustained system of systems, driven by user needs. GEOSS should be flexible and evolvable in that it supports a broad range of implementation options, allowing observing system developers to reflect the best available understanding of the observation impacts and results, and providing observing system developers the flexibility to use the most appropriate technologies, observing approach, platform, and vantage point. GEOSS should be innovative in its ability to incorporate new technology, methods, and collaboration arrangements.

2.3.2 Scope – GEOSS will address all observations required within the application areas necessary for participants to make products, forecasts, and related decisions. GEOSS will include system components required to collect, exchange and disseminate observational data and information, as well as the planned and operational systems required to acquire the observations.

2.3.3 Capabilities - GEOSS should be composed of observing, processing, and dissemination capabilities, provided by national, regional or international agencies that subscribe to GEOSS while retaining their ownership and operational responsibility. Each capability:

- will include all those of the individual component observing systems provided by agencies as well as those mutually agreed upon by participants;
- will provide for agreed-upon protocols/methods/standards and necessary interfaces following a global interoperability specification, which shall be agreed upon and adhered to by all participants.

2.3.4 Data and its exchange and dissemination - GEOSS should ensure that data and products are observed, recorded and stored in clearly defined formats;

- to have quality indications so that users can evaluate their value;
- to be archived in defined formats and maintained as accessible data sets;
- to have metadata information that enables search and retrieval by users;
- to provide access to all required observations at national, regional and global scales (required observations are described in the User Requirements report and Data Utilization report).

2.3.5 Operation - GEOSS should provide a framework for securing the future continuity of observations and stimulating new observations by:

- reviewing the needs against existing data sets and thus defining gaps (and duplications) in the needs;
- greater coordination of acquisition planning over longer terms;
- working with GEOSS participants to support the development of systems to fill gaps;
- promoting a broad awareness of the Earth observations needs and shared benefits through open collaboration among participants, and by giving funding entities measures of value and return to support investment decision-making;
- working to improve cost effectiveness by coordination of all systems;
- encouraging mechanisms to promote research and to effectively transition from research to operational modes based on user needs and technical feasibility.

2.3.6 Catalogue - In aggregate, the catalogued components of GEOSS must include all observations needed to satisfy the identified user requirements and comply with the data utilization requirements. The
officially recognized catalogue of member and participating organizations and the components they support will be maintained collectively under the auspices of GEOSS. That catalogue system will be publicly accessible, network distributed, and interoperable with major Earth observations catalogues.

2.4 Components

From a functional view (see Figure 2.2), GEOSS will include the following components: a component to acquire observations based on existing national, regional and global systems to be augmented as required by new observing systems; a component to process data into useful information; and a component required to exchange and disseminate observational data and information. Components are understood to include data management that encompasses issues such as QA/QC (Quality Assessment/Quality Control), access to data, and archiving of data and other resources.

![Three components of GEOSS](image)

**Figure 2.2: Three components of GEOSS**

2.4.1 Observations - GEOSS will consist of remotely sensed and in situ systems. The remotely sensed and in situ systems will include various automated and manual components, given that individual systems remain within their mandates.

2.4.2 Data Processing - The data processing component will consist of national, regional and global data centers, as well as discipline data centers, which will process remotely sensed and in situ observation data and retrieve required geophysical parameter information. An integrated approach to sharing various sources will be supported in order to generate global data sets, which is also necessary for climate research and other activities.

2.4.3 Data Exchange and Dissemination - The data exchange and dissemination component will provide the necessary data and access to designated centers, including those for archive as well as on-demand access. This component will also provide interoperability between individual observing systems. The GEOSS architecture requires agreed-upon interoperable interfaces among components. The data exchange and dissemination component will improve data sharing by facilitating access to data and to metadata about holdings and planned acquisitions.

As GEOSS participants operate systems within their mandates, many varieties of communications technologies will be in use, including but not limited to the Internet. For instance, observation collection systems may involve data exchange among satellites in orbit or floppy disks sent by mail from remote rain forest locations; disaster-warning systems may involve broadcast TV alerts and messages displayed on highways. (Detailed requirements will be described elsewhere in the GEOSS Implementation Plan.) GEOSS will draw on existing Spatial Data Infrastructure (SDI) components as institutional and technical precedents in areas such as geodetic reference, common geographic data, and standard protocols.
2.5 Interoperability

Interoperability across GEOSS depends crucially on specific interface agreements. GEOSS participants must agree on interoperability technical specifications to which individual system components will adhere. A GEOSS process for reaching agreements must be established and sustained, and must include discussions with major international programs and consortia such as GMES (Global Monitoring for Environment and Security), INSPIRE (Infrastructure for Spatial Information in Europe), and ESMF (Earth Science Modeling Framework), among others.

All GEOSS agreements are subject to the broad policies agreed among GEOSS participants, described in the Data Utilization report. Agreements must be sensitive also to the needs of all GEOSS participants, including technology and accessibility disparities across the range of participants.

2.5.1 Agree on interoperability objective – As a system of systems for Earth observations, GEOSS will need to encompass many existing and future individual observing systems that are separately managed by management domains at any level of government, as well as possibly by commercial, academic, and other non-government organizations. This objective demands high interoperability—that is, differences among systems must not be a barrier to tasks that span those systems. Because interoperability agreements must be broad and sustainable, fewer agreements accommodating many systems are preferred over many agreements accommodating few each.

2.5.2 Focus on interfaces – Participants will agree to use common protocols, standards, and interoperability specifications for observing, processing, and dissemination capabilities. Interoperability specifications need only define how system components interface with each other. In this way, such a specification minimizes any impact on affected systems other than where they interface with the shared architecture. . This interoperable interface approach helps to assure that interoperability costs are kept at a reasonable proportion to the benefits expected.

2.5.3 Open, international standards based on specific needs – To achieve practical interoperability, agreements must be driven by specific needs as they are identified at the actual interfaces among active participants. Wherever possible and to the maximum extent possible, interoperability agreements must be based on non-proprietary standards, and profiles must be specified when standards are not sufficiently specific. Rather than defining new specifications, GEOSS should adopt standard specifications agreed upon voluntarily and by consensus, with preference to formal international standards such as ISO. All interface implementations should be specified in a platform-independent manner, and verified through interoperability testing and public demonstrations.

2.5.4 Design for components and services – The agreements should be based on current information technology directions that emphasize interoperability through component-based and service-oriented information architectures. These interoperability agreements align with standards bodies and broad government policies, as well as with "enterprise architecture" recommendations of groups such as the Industry Advisory Council 1.

The information architecture of GEOSS needs to leverage the ongoing evolution of information technology toward design of complex systems as assemblies of components. Software components of modern systems are now being designed to interoperate primarily by passing structured messages, as is typical in network interactions. The set of operations exposed at a component interface is known as a

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1 The Industry Advisory Council represents more than 375 leading information technology companies worldwide that have significant government business interests.
“service definition.” By expressing interface interoperability specifications as standard service definitions, GEOSS system interfaces assure verifiable and scalable interoperability, whether among components within a complex system or among discrete systems.

2.5.5 Document service interfaces – Interoperability within GEOSS depends crucially on technical interfaces typically described through standard service definitions. Such service definitions should specify precisely the syntax and semantics of all data elements exchanged at the service interface, and should fully describe how systems interact at the interface. At present, participants in GEOSS should agree to use any one of four open standard ways to describe service interfaces, and to convert to a single standard if that becomes appropriate in the future.2

2.5.6 Avoid non-standard data syntaxes - There are many ways to represent data and each has its particular strengths and weaknesses. Especially troublesome from an interoperability perspective is the fact that conversion between different data representations can degrade the data. It is therefore very important that participants avoid non-standard data representations and agree to use precisely defined syntaxes for data that traverses system interfaces. Some syntaxes traditionally used by Earth observations communities will persist for many years, but networked systems should support robust and generalized standard data syntaxes.3

2.5.7 Register the semantics of shared data elements - Interfaces among participant systems in Earth observations typically involve a large number of data elements. In this situation, it is a non-trivial task for participants to gain a common understanding of the meaning of data elements defined at the interface. Therefore, a standard4 for representing such understandings in a commonly accessible registry is needed. This standard will support registration of data using virtually any syntax, and also provide a basis for interoperability among data dictionaries and registries.

2.5.8 Standards for archiving of data and other resources - Assuring interoperability in archiving is a significant but very important challenge. Accordingly, GEOSS will be advised in its adoption of standards by communities with particular expertise in archiving, such as those data managers associated with the World Data Center program managed by ICSU (International Council for Science).

2.5.9 Implement the standard search interface - One of the agreements among participants in the GEOSS is to jointly maintain a catalogue of member and participating organizations and the components that comprise GEOSS. This catalogue is to be publicly accessible, network distributed, and interoperable with other major Earth observations catalogues.

Many Earth observations catalogues that require interoperability at the search service have adopted the international standard used for catalogue search (ISO 23950 Protocol for Information Search and Retrieval). This search service is interoperable with the broadest range of information resources and services, including libraries and information services worldwide as well as the "Clearinghouse" catalogues supported across the Global Spatial Data Infrastructure now implemented in more than 50 nations. This standard search service also has demonstrated interoperability with services registries using either an ebXML metadata model or UDDI (Universal Description, Discovery, and Integration).

2 The standards are CORBA (Common Object Request Broker Architecture), WSDL (Web Services Definition Language), parts of ebXML (electronic business, eXtensible Markup Language), and UML (Unified Modeling Language).
3 The international standard ASN.1 (Abstract Syntax Notation) and the industry standard XML (Extensible Markup Language) are examples of such syntaxes, and are themselves inter-convertible.
4 ISO 11179 (formally designated ISO/IEC 11179, Information Technology—Metadata Registries) is an international standard for information about data (metadata).
2.5.10 Implement the standard services for geospatial data - In GEOSS especially, data and information resources are typically referenced to a place on the Earth. Such “geospatial data” may be viewed in the form of a map but the underlying digital data is usefully applied in many other forms as well. Interfaces to discover and use these data and services have been standardized, ranging from “yellow pages” and “product catalogues” down to “technical manuals”. International standards supporting discovery of and access to geospatial data and services are agreed upon through the various Spatial Data Infrastructure initiatives. These include the ISO 23950 search service interface standard, as well as a range of ISO standards covering documentation and representation, and place codes. OGC (OpenGIS Consortium) specifications for Web Mapping Service, Web Coverage Service, and Web Feature Service are examples of publicly available standards on geospatial services.

The standard services for search and for geospatial data are examples of interfaces that support the component-based, service-oriented architecture of GEOSS. These services are defined using a network communications model with precisely defined requests and associated responses. The syntax and semantics of the message elements exchanged at the interface are also precisely defined and registered. Further, these standards were initiated by industry-led groups such as the OGC, which represents more than 220 organizations. In this and other voluntary, consensus-based processes, potential standards are developed with broad input and are implemented and fully demonstrated before being advanced to become international standards maintained by ISO over the long term. In the instances cited, the service standards are widely deployed in commercial products and are also available for free as open-source software implementations.

2.6 Expanded Functional and Behavioral View of GEOSS

Sections 2.2 and 2.4 described initial considerations for defining an actual and credible GEOSS architecture and an initial GEOSS functional view, respectively. To elaborate those initial considerations further, the following section describes supplemental views that:

- Illustrate the linkage among GEOSS components, beginning and ending with user requirements (the social and economic drivers of GEOSS);
- Bring together the work of the Sub Groups (especially Architecture, Data Utilization, and User Requirements and Outreach);
- Begin to define the scope of GEOSS by presenting architectural options (or variants) within the agreed upon (at GEO-2) system of systems architecture;
- Address the linkage of individual members’ and participating organizations’ “information and products” to that of GEOSS.

Section 2.6 presents additional views designed to address these topics and to facilitate GEO’s effective transition from the Framework Document to the 10-Year Implementation Plan.

2.6.1 System Architect Functions – The GEOSS Architects should at a minimum consider the following attributes:

- Take a holistic view, giving interactive consideration of form and functions. Notional GEOSS functions will be discussed in a following subparagraph. GEOSS form will be determined not only by potential architecture solutions, but also by the GEOSS organizational mechanism (being addressed at length by the GEO Sub Group on International Cooperation).
• Consider GEOSS lifecycle roles. The development of a comprehensive, coordinated and sustained GEOSS will necessitate stable intermediate forms in an evolutionary, incremental development.
• Spend a large amount of time communicating. Architecture descriptions must be communicated and explained and their integrity maintained.

The complexity of the GEOSS Architecture is further illustrated by considering the following two common architecting scenarios:

• Reverse architecting
  o “We have this collection of systems. We think by finding some organizing architecture over it, we’ll be able to achieve some of the things we want (e.g., greater interoperability, reduced cost).”
• Uncertain future choice
  o “We don’t know what exact system we’ll want in the future, but we have to make some investments now. Help us define what these investments should be given the future’s uncertainty.”

Both these scenarios appear to apply to the GEOSS Architecture; there are many others that also likely apply. These scenarios are presented to illustrate the need for views that help reduce the architecting complexity into a series of manageable tasks.

2.6.3 A Functional/Behavioral Model – Figure 2.3 presents a functional and behavioral model of how Earth observation information is collected, processed and delivered to GEO members and participating organizations. This type of common view of GEO members’ Earth observation system is essential to determining the GEOSS Architecture options (to be discussed in Section 2.6.4).
This view displays five interrelated functional segments:

- Stakeholder Interface
- Earth Observations (collection of data)
- Access and Archives
- Data Processing and Models (geo-products)
- Methodology, Innovation and Implementation (MII)

The arrows in Figure 2.3 depict the behavioral nature of this view—the flow of information (data exchange and dissemination) among the various segments, beginning and ending with the stakeholder (e.g., users of Earth observation information). The model illustrated in Figure 2.3 provides one view that addresses all the questions posed by the GEO Plenary and Subgroups and allows a series of GEOSS variants to be developed and evaluated.

2.7 Functional/Behavioral Model Application to GEOSS Variants – At GEO-2, the Plenary agreed that the preferred architecture of a comprehensive, coordinated, and sustained Earth observation system or systems would be a “system of systems.” At GEO-3, the Plenary agreed to recommend (via the Framework Document) that this system of systems would be called the Global Earth Observation System of Systems (GEOSS). At both GEO-2 and GEO-3, members and participating organizations discussed at length and agreed that GEOSS would include data transformation into “information”, i.e. geo-products which are to be considered as part of GEOSS, recognizing the value of modelling, integration and
assimilation techniques for example global sea-surface temperature fields. Such geo-products will be prepared in those modeling centres participating in GEOSS and would serve as input to the decision support systems required in response to societal needs.

To develop a GEOSS option (or variant) model, envision each GEO member or participating organization operating within its own mandate, similar to that illustrated in Figure 2.3. Next, consider GEOSS as a multi-layered construction of such organizations. In essence, many GEOSS participant operate an Earth observation system of systems today. Therefore, one can envision GEOSS as a system of “system of systems.” With that view, one can then determine a series of GEOSS options. The following list is a small subset of possible options to consider, but illustrate the thought process:

- **Option 1**: Link only Earth Observations.
  - This option is probably the simplest option. By linking only the Earth observation systems, GEOSS participants have a much more robust set of initial data with which to operate within their existing mandate. Additionally, this option directly ties to one of the principal agreements of the Earth Observation Summit Declaration—GEOSS will be based on existing systems.

- **Option 2**: Link Earth Observations and add a linkage of access and archive capabilities (e.g., regional).
  - This option (illustrated in Figure 2.4) expands on the first option and illustrates an evolutionary pathway for GEOSS.

- **Option 3**: Link Earth observations, add an access/archive linkage, and add a data processing linkage in a particular area of interest (e.g., a global SST product).
  - This option continues the evolutionary progression toward a more complex GEOSS.

- **Option 4**: Same as Option 3, but expand to multiple areas of interest within the GEOSS agreed data transformation function.

Again, these options are offered to begin the dialogue on logical GEOSS options to be addressed with the 10-Year Implementation Plan. One could expand any of these options to numerous sub-options. For example, one could modify Option 1 to provide the functional linkages among only access and archive segments or among only data processing segments. For each option selected, the GEOSS Architects will need to determine strengths and weaknesses of each selected option, as well as illustrate how that option meets the requirements of GEOSS (e.g., clear linkage to societal benefits). The initial set of GEOSS options will likely be those that best match the combination of met requirements, political will, available resources, and available technology. However, those initial options may well change throughout the 10-year period of the initial Implementation Plan, as requirements change, political will evolves, and technology advances.
2.7.1 Summary – This section discusses the need for an inter-related series of architecture views or models that allow the proper illustration and communication of GEOSS options to GEOSS participants. Figures 2.3 and 2.4 are offered as additional views that address questions and concerns from the GEO Plenary and Subgroups and that may allow an effective transition from concepts in the Framework Document and GEO Report into the beginnings of an effective Implementation Plan.

Glossary:

ASG: Architecture Sub-Group
ASN.1: Abstract Syntax Notation
CORBA: Common Object Request Broker Architecture
ebXML: electronic business, eXtensible Markup Language
ESMF: Earth Science Modeling Framework
GEO: *ad hoc* intergovernmental Group on Earth Observation
GEOSS: Global Earth Observations System of Systems
GMES: Global Monitoring for Environment and Security
ICSU: International Council for Science
IDL: interface definition language
INSPIRE: Infrastructure for Spatial Information in Europe
OGC: OpenGIS Consortium
QA: Quality Assessment
QC: Quality Control
SG: Sub-Group
SDI: Spatial Data Infrastructure
UDDI: Universal Description, Discovery, and Integration
UML: Unified Modeling Language
URSG: User Requirement Sub-Group
WSDL: Web Services Definition Language
XML: Extensible Markup Language