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Integration of Earth Observation Data: Challenge of GEOSS

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Abstract

The GEO (Group on Earth Observations), a voluntary partnership of governments and international organizations, was established at the Third Earth Observation Summit in February 2005 to coordinate efforts to build a ***Global Earth Observation System of Systems, or GEOSS****. This article describe the efforts of and present issues in developing GEOSS with SoSE (System of Systems Engineering) approach..*

1. GEOSS; Its backgrounds and objectives

"Understanding the Earth system—its weather, climate, oceans, atmosphere, water, land, geodynamics, natural resources, ecosystems, and natural and human-induced hazards"—is crucial to enhancing human health, safety and welfare, alleviating human suffering including poverty, protecting the global environment, reducing disaster losses, and achieving sustainable development. Observations of the Earth system and the information derived from these observations provide critical inputs for advancing this understanding.

The GEO (Group on Earth Observations), a voluntary partnership of governments and international organizations, was established at the Third Earth Observation Summit in February 2005 to coordinate efforts to build a Global Earth Observation System of Systems, or GEOSS. As of March 2009, GEO's Members include 77 Governments and the European Commission. In addition, 56 intergovernmental, international, and regional organizations with a mandate in Earth observation or related issues have been recognized as Participating Organizations.

The 10-Year Implementation Plan Reference Document of GEOSS (Global Earth Observation System of Systems) states the importance of the Earth observation and the challenges to enhance human and societal welfare. This Implementation Plan, for the period 2005 to 2015, provides a basis for GEO to construct GEOSS. The Plan defines a vision statement for GEOSS, its purpose and scope, and the expected benefits. Prior to its formal establishment, the Ad Hoc GEO (established at the First Earth Observation Summit in July 2003) met as a planning body to develop the GEOSS 10-Year Implementation Plan.

The purpose of GEOSS, as illustrated with Fig.1, is to achieve comprehensive, coordinated and sustained observations of the Earth system to meet the need for timely, quality long-term global information as a basis for sound decision making, initially in nine societal benefit are:

Figure 1. Concept of GEOSS

(1) Reducing loss of life and property from natural and human-induced disasters;
(2) Understanding environmental factors affecting human health and well-being;
(3) Improving management of energy resources;
(4) Understanding, assessing, predicting, mitigating, and adapting to climate variability and change;
(5) Improving water resource management through better understanding of the water cycle;
(6) Improving weather information, forecasting, and warning;
(7) Improving the management and protection of terrestrial, coastal, and marine ecosystems;
(8) Supporting sustainable agriculture and combating desertification;
(9) Understanding, monitoring, and conserving biodiversity.

GEOSS is a step toward addressing the challenges articulated by United Nations Millennium Declaration and the 2002 World Summit on Sustainable Development, including the achievement of the Millennium Development Goals. GEOSS will also further the implementation of international environmental treaty obligations.

2. System of Systems Engineering and its Application to GEOSS

2.1 SoSE Approach

The "A System-of-Systems (SoS) is a "super-system" comprised of elements that are themselves complex, independent systems which interact to achieve a common goal." In the context of this definition, attributes of a system of system are that the component systems achieve well-substantiated purposes in their own right even if detached from the overall system. In fact, the components systems are managed in large part for their own purposes rather than the purposes of the system of systems (SoS). To then justify the creation of a system of systems, the SoS must exhibit behavior, including emergent behavior, not achievable by the component systems acting independently. Thus, the SoS is offering significantly new capabilities that justify the "overhead" associated with the SoS.

To take advantage of the processes and technologies available for advanced system of systems such as GEOSS, an engineering approach is desired which provides systematic means to evaluate the design and implementation of the system of systems. To this end, the SoSE Process used should be architecture-centric, model-based, and user-driven (Pearlman [2006]). Architecture-centric means that the SoS architecture model serves as the primary artifact for conceptualizing, constructing, managing, and evolving the SoS under development (see Figure 2). The architecture model facilitates dialog between stakeholders by having a common notation and an intuitive depiction of the system structure and behavior.

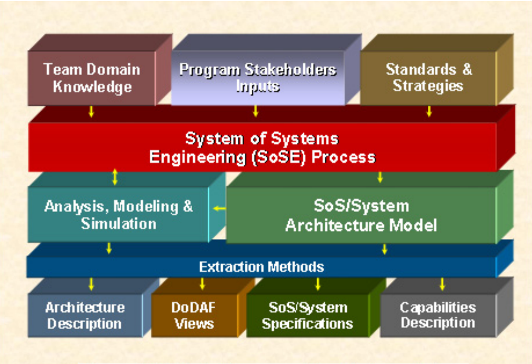

Figure 2 A block diagram of the SoS provides a visualization of the process flow

At a glance, an observer may imagine that GEOSS is a typical System of Systems. GEO aims at building GEOSS on existing Earth observation systems by adding value through synergy and not building a system level capability from scratch.

2.2 Challenges of GEOSS from SoSE Perspective

However, for a number of reasons, the GEOSS development process is quite different from conventional examples of SoSE applications reported in Butterfield, et al. (2007) and Martin (2007), which refer to the cases of Boeing and NASA. Private firms and governmental organizations like Boeing and NASA have a hierarchical and/or network structure of specialized divisions to efficiently achieve missions of the organizations. The challenge of SoSE, in this traditional context, is to show how to realize efficiently, with minimum risk, a SoS that contributes to achieving the organizational mission through integrating large-scale and complex systems.

In contrast, while GEO is also an organization consisting of members that share the common objectives, it is a voluntary partnership of national governments and international non-profit organizations. GEO cannot force the participation of members to develop GEOSS.

To understand the differences, it is valuable to compare two cases, one of a SoS built by an organization with a single large customer focal point, typically under contract, and the other of an organization which creates the SoS from voluntary contributions (GEOSS). Attributes of the two cases are shown in Figure 3 (Pearlman 2006). The differences are more than just the contractual verses voluntary nature of the SoS. GEOSS has very large cultural and technical capability differences that impact the way the SoS needs to be constructed so that it effectively serves the customer base, i.e., the scientists, industry members, and government managers that create and use information for societal benefits. An interesting example of the issues is in standards. One might ask: "Aren't standards globally standard?" Many instances show that different cultures independently derive standards, as they do languages. There are many words in different languages to address the same object or thought. So there are multiple definitions of how to measure physical attributes of the Earth, such as sea level. This leads to the challenges in GEOSS of creating translatable taxonomies, standards, and measurement techniques to attain a global observation and information set. A major thrust of GEO is that differences in systems cannot be a barrier to tasks that must span multiple systems. Yet the System of Systems must be "constructed" without imposing significant new constraints on the existing or legacy systems. Thus the critical question in formulating the SoS is: "what few things must be the same so that everything else can be different."

Traditional SoS Environment	GEOSS Environment
• Uniformity of objectives • Single corporate direction • Cultural uniformity • Common Technology • Data standards and quality established	• Disparate motivations • Competing agendas • Diverse backgrounds • Significantly varying technology levels • Multiple views of data standards and quality

Figure 3 Conventional SoS and GEOSS differ in the underlying constraints that drive their development and operation

GEOSS has additional constraints that evolved from its basic principles of development and operation. For example, in addition to the cultural and standards diversities mentioned above, GEO cannot provide financial support and human resources to develop GEOSS, because the mission of GEO is limited to the coordination of activities to facilitate the development such as organizing meetings and sponsoring outreach. Development of a SoS usually requires additional cost for modification of interfaces and enhancement of systems for an expected increase in computational load and so forth. Moreover, to provide equal opportunities to join in the development of and then GEOSS, GEO needs to use non-proprietary and open interface standards as much as practical.

Consequently, to develop GEOSS, consensus has to be built among governments and participating organizations on the targets and the process of design and implementation, that may lead to the endorsement of actions on a voluntary basis.

Under such circumstances, the objectives of applying SoSE to GEOSS are to:

(1) Maximize the participation of governments and the other organizations.

(2) Encourage voluntary activities such as the contribution of data and systems, promotion of system integration to achieve GEOSS targets.

(3) Coordinate the activities efficiently to build usable and reliable GEOSS.

4) Create and maintain a clear understanding of the

social impacts and benefits of synergy derived from operation of the SoS.

These provide a new challenge of SoSE as follows:

(1)How to accelerate consensus building among diversified participants not only on abstract objectives of SoS development, but concrete design and deployment process of SoS?

(2)How to encourage and organize coordinated activities on a voluntary basis towards a SoS development?

(3)How to make sure that voluntary activities lead to the consistent and robust SoS development that can successfully fulfill user requirements of nine SBA's?

(4)How to assure that the wide range of technical and domain knowledge can be supported by the SoS without reducing the products and infrastructure to the lowest common level?

In the future, a SoS will expand beyond the boundary of individual organizations to provide a variety of common and advanced services to society. ITS (Intelligent Transport System) would be a good example, because it requires tight collaboration among car manufacturers, part manufacturers, wireless communication carriers, road administrative organizations, polices and so forth. In the case of disaster warning and mitigation, a number of public organizations (not limited to disaster prevention agencies) must coordinate to provide emergency services such as rescue and replacement of critical infrastructure. How to efficiently develop a SoS at societal scale beyond the boundary of individual organizations is a very important research challenge that provides large benefit to society.

One of the most successful and popular examples of a systems of systems is the WWW (World Wide Web). A number of systems are now interconnected through Web technologies. The web itself, however, evolved only after a limited number of basic interface standards such as HTML, HTTP and associated technologies were established. It may be referred to as a successful evolution model in analyzing what kinds of standards and technologies would be well accepted by a wide range of developers and users. However, the WWW is different from GEOSS in the sense that GEOSS has to be developed based on existing systems that already run on established standards that may not be completely interoperable or accepted by different communities.

"The Cathedral and the Bazaar" (Raymond (2006)) illustrates the contrast between the new and traditional challenges of SoSE. The author compares building a cathedral to top-down and centralized development of systems, while distributed and collaborative system development based on many voluntary works (like Linux) is called "Bazaar" model. His major finding for the success of the Bazaar model is the fact that a complete working prototype system and not just parts of a system, though it may be small and has only limited functionalities, has to be presented early to attract and stimulate the interests and voluntary participation of software engineers. Once enough volunteers are mobilized, the initial prototype system can be improved and sometimes completely replaced with the new one, to be a higher quality and reliable system.

3. SoSE activities for GEOSS

As described in section 2.1, the key to success of GEOSS depends on how to

1) maximize the participation of governments and international participating organizations,

2) encourage voluntary activities such as the contribution of data and systems, promoting system of systems integration to achieve GEOSS targets,

3) coordinate efficiently the activities to build a usable and reliable GEOSS.

To meet these objectives, three types of complementary approaches should be considered: visualizing both the available resources and the benefits from committing these and additional resources; providing incentives for membership through reduced net cost or equivalent benefits; and promoting coordination and evolution of formulation through work plan tasks that lead to understandable and unique efficiencies.

3.1 Visualizing Available System and Technical Resources

The first approach is to visualize available technical resources for the building of GEOSS and a future blueprint of GEOSS that presents a direction for both the development and the structure of the outcomes. They are categorized as follows:

1) Blueprint or future prospects of GEOSS

2) User requirements,

3) Data systems, services and vocabulary used for description of metadata.

4) Standards and interoperability arrangements,

5) Best Practices, and quality assurance

6) Case studies, lessons to be learnt, human resources.

1) Blueprint or future prospects of GEOSS

As the GEOSS 10-Year Implementation Plan states, "GEOSS builds on and adds value to existing Earth observation systems by coordinating their efforts and addressing critical gaps", but no detailed plan or design is presented. Instead, 10-Year Implementation Plan Reference Document (2005) provides a conceptual model (Figure 4).

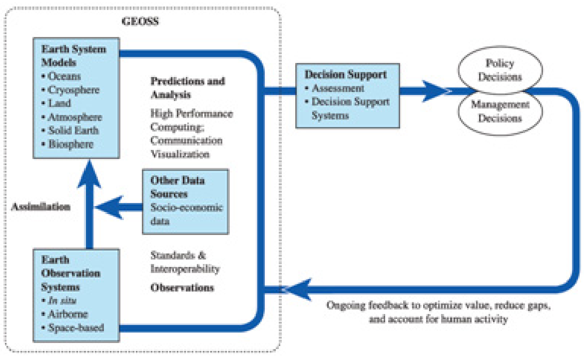

Figure 4 Conceptual architecture of GEOSS
"This diagram demonstrates the end-to-end nature of data provision, the feedback loop from user requirements and the role of GEOSS in this process. The primary focus of GEOSS is on the left side of the diagram."
(10-Year Implementation Plan Reference Document (2005))

2) User requirements

User requirements are important resources because they provide the basis of system design. In the practice of ordinary system engineering and SoSE, user requirements are not regarded as "resources" for system development and integration because clearly-stated user requirements are premises for the plan and design. GEOSS users, as discussed earlier, are very diversified and geographically dispersed in different socio-economic and cultural contexts. Also, in this environment, some factors may be "invisible" in the early engineering phase, even though they may play important roles in alleviating human sufferings in local environment. This creates the necessity that activities of exploring and identifying user communities and of extracting/organizing their requirements needs to be clearly defined in the process of SoSE for GEOSS. User requirements have to be registered and visualized for GEO members or participating organizations so they may be balanced and incorporated in the planning of the SoS. A registry of user requirements is now being designed.

3) Data systems, services and vocabulary used for description of metadata and standards

In addressing the GEOSS concept, the engineer tends to focus on data and the systems for acquisition, storage, and distribution. This focus is too narrow, because the products are information sets which are derived from models and analyses. Thus the systems engineer must consider interoperability and standardization of model outputs. In the context of GEOSS, this extension can be challenging because the system is bringing together disparate communities such as biodiversity and climate which have limited common descriptions and standards.

Thus, data, models, systems and services are building blocks of the SoS. Since the focus is on bringing together existing and new systems, information on available and well-accepted standards is indispensable in interlinking systems and in disseminating and sharing data and information. GEO established component/service registries and standard registries for this purpose (http://geossregistries.info/). Figure 5 shows the registries in GEOSS information system structure. The component registry allows contributors to register metadata on components (system and data) together with those on interfaces to access systems and data. 237 components and 192 service interfaces are already regis-

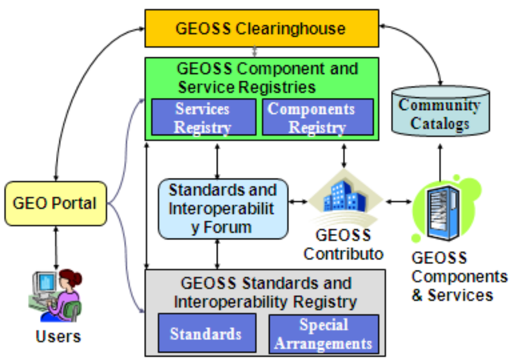

Figure 5 Initial Operating Capabilities of GEO (Pearlman (2007), Report of the GEO Architecture and Data Committee (ADC) for the GEO Plenary Cape Town)

tered (as of March, 2009). Each of these components may offer one or more services, generally with automated interfaces. Thus a companion registry, the service registry, enables users to understand the full range of services available through GEOSS. The engineer might question the reason for maintaining a component registry. By clearly defining the components through entry into the components registry, both the heritage of the services can be traces and the component supplier is committing to follow the interoperability agreements of GEOSS.

4) The interoperability agreements

The interoperability agreements fall into two classes, those which are formally defined standards and those employing special arrangements that are commonly recognized, but not (yet) formalized through international standards organizations. There are cases of special interoperability arrangements in commonly accepted arrangements such as the Adobe "pdf" which are in wide use. The special interoperability arrangements are needed because – as noted earlier – GEOSS is a voluntary system and the SOS operators cannot impose significant new demands on existing contributed components. Standards and special arrangements, registries for both GEOSS recognized standards and GEOSS interoperability arrangements have already been established. The primary focus initially was on standards used by the contributed observing components. This has been expanded and it is anticipated that interoperability of models will be added as a focus for the standards efforts of GEOSS. The registration process was initiated in the June, 2007 and further improvement of the registries will continue based on feedbacks from users.

Data vocabulary such as data item names and underlying definitions provide a semantic basis to support the consistent and easy-to-understand description of metadata, a key to GEOSS interoperability. This is important both for machine readability and for working in a cross-cultural, cross-discipline environment. So far, the standardization on format and encoding rules, i.e. syntactic aspects of data and interfaces have been a primary concern in discussions about interoperability. These are typically done within a technical disciple. However, when users need to discover and integrate data and services provided across different disciplines, semantic interoperability will be one of the key issues. A registry of data vocabulary has not yet been established though some terminologies are already registered as components in the component registry. Development of the registry of data semantics or vocabulary is being developed by taking into account the balance between the complexity of descriptions and the value of detailed description of meanings.

5) Best Practices

A method to significantly improve interoperability is to delineate best practices which are followed in the collection and analyses of data. In some instances, this would correlate closely with the work on semantics discussed in the previous section. An example would be the definition of sea level, which is not globally uniform. A corollary would be to define a best practice in the measurement techniques and perhaps instrumentation for such sea level measurements. While it is recognized that best practices occur in all aspects of GEOSS, they are difficult to refine in detail due to the variety of techniques and the availability of technology. Since it is unlikely that a best practice is absolute in nature, it requires consensus development through peer review to converge to recommended best practices. To accelerate the creation of a compendium of best practices while maintaining the peer review process, GEOSS has instituted a web-based wiki (http://wiki.ieee-earth.org). While this requires some editorial oversight, the open forum nature of the wiki allows broad community participation.

6) Case studies, Lessons to be Learned, Human Resources

Information on SoS design and implementation for individual SBA applications, ranging from the extraction and definition of user requirements to the delivery of observation-based information, is very important in promoting and helping the SoS design and applications in associated fields. Such information could be considered as Best Practices, Lessons Learned, and Case Studies associated with information applications. These has been substantial development of case studies, those used for assessing and validating interoperability for cross-discipline developments (the Interoperability Process Pilot Project - reference: Siri Jodha Singh Khalsa 2007)) and those which look in depth at a single discipline (AIP use cases - reference Percivall 2007b).

3.2 Providing incentives and reducing cost

Once the registries are established to visualize available system and technical resources for GEO members, the critical steps are populating the registries and encouraging their usage as well as the use of other resources of the SoS. More specifically, for data and system providers, the incentives and cost of contributing components are of importance. SBA users may be concerned about the cost of finding information, the appropriate best practices and contributing user requirement information. This includes also the issue of stability and sustainability of the data streams. The issue here is not just the monetary expenses, which should be minimal, but also the personnel time to use the system. To reduce the cost of registration, metadata items for registration should be minimized. Present GEO component, service and standards registries require only a minimum set of metadata, basically with a free text description, which enables users to find relevant information.

To contribute to reducing the cost of building a SoS, more detailed and structured description of components should be encouraged. Also standards used in the contributed components should be preferentially non-proprietary and open ones, such as ISO and IEEE standards. Only from technical viewpoints of reducing system integration cost, will GEO request the generation of new standards and request GEO members to these where appropriate. When GEO identifies gaps between the available standards and the demand for better interoperability, it will encourage existing standardization organizations to work with GEO and members/participating organizations. When contributed components useful to GEOSS are not consistent with internationally accepted interface standards, GEO may consult with the component providers to alleviate the interoperability issues. The Standards and Interoperability Forum (SIF), a group of voluntary experts under the supervision of ADC, was formed to help providers register standards/interoperability arrangements and to recommend the creation of new standards to standardization bodies. The terms of reference provide more details of the SIF charter and operations (Khalsa 2007b)

To the further promotion of component registration and uses for SoS building, incentives have to be visualized, in addition to the cost reduction. Counting the number of contributed components by organizations and information on who downloaded which components could benefit component providers. Registration of practices in the Best Practice wiki can more directly lead to the benefits to data/system providers and SoS builders as well, but improving and facilitating interoperability early in the data and information creation. The incentives of contributors are basically determined by how visible GEO activities are from the world audience. For example, 91 organizations offered participation and supported development in the Architecture Implementation Pilot to present demonstrations of GIS-based data integration during 2006 and 2007 at the Ministerial Summit at Cape Town in November, 2007.

Contribution of GEOSS to society, however, has to be evaluated by how GEOSS can contribute to better decisions of SBA users. Outcome indicators of GEOSS need to be developed. This aspect will be touched upon in the next section.

3.3 Promoting Coordination and Evolution of Tasks in the Work Plan

In the work plan of GEO, tasks are defined to achieve and promote the development and application of GEOSS. These tasks were originally proposed by GEO members and driven by voluntary participation. While initial operating capability such as registries of components and standards are established to visualize and distribute the available resources, supporting task activities in pursuing the targets and encouraging GEO members to propose new necessary tasks in a timely manner is crucially important for the success of building GEOSS. In addition, to ensure that task teams can help each other, and to maximize the synergy effects of task achievements, encouraging and coordinating better collaboration among tasks is also needed.

For the task coordination, GEO needs to share an "overview map" showing:

1) how well the goals of GEOSS for each SBA are achieved by GEO activities, and how well individual tasks contribute to the achievement of overall goals;

2) where tasks are positioned and how they are associated with each other in the flow of Earth environmental data from observation to SBA applications, and how contributed components and standards are used by the tasks; and

3) which areas need to be covered by new tasks and which tasks need to be strengthened to fill the gap between present capabilities and user requirements?

Visualizing how each task is linked with the achievement of the overall goals of GEOSS is quite effective, as shown by the application of architecture model to earth observation systems of NASA (Martin, 2007, Fig.6)

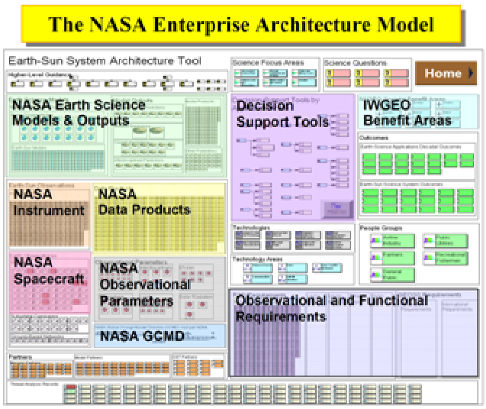

Figure 5 NASA Enterprise Architecture Model (Martin (2007) Value Assessment of GEOSS; Using an Architectural Model, Presented at the IEEE GEOSS Workshop –Implementing a System of Systems)

3. Concluding Remarks and Future Prospects

GEOSS is a significant international endeavor to strengthen links from Earth observation to SBA applications through the integration of individual observation systems with the use of advanced information technologies. From the viewpoint of SoSE, building GEOSS is also an important challenge of how to enable heterogeneous systems developed by different organizations in different contexts to behave like a unified system of systems in order to realize such large societal benefits that could have never been provided by individual systems operating by themselves. The voluntary nature of GEOSS and its breadth as a global collaboration make this SoS development unique. GEO has finished building an initial operating capacity which includes the basic structural components such as registries, portal interfaces and data discovery capabilities. Using the success of the "Bazaar" model approach, GEOSS is establishing the building blocks in the registries that will accelerate spontaneous activities toward the more complete and comprehensive development of the SoS. In the next steps during 2008, GEOSS will broaden the use of these capabilities through individual task achievements focusing on applications that provide substantial benefits to society.

Footnote: This article is based on personal experiences of the authors in GEOSS and in developing SoS applications and does not represent the official opinions of GEO.

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