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Coordinating an Observation Network of Networks EnCompassing saTellite and IN-situ to fill the Gaps in European Observations

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"Navigating Sustainability on a Changing Planet"

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Acronyms

ConnectinGEO ConnectinGEOCoordinating an Observation Network of Networks EnCompassing saTellite and IN-situ to f ll the Gaps in European Observations

CoP Community of Practice

DAB Discovery and Access Broker

ELSS Earth's life support system

EO Earth Observation

EV Essential Variable

EBV Essential Biodiversity Variable

ECV Essential Climate Variable

EGBV Essential Global Boundary Variable

EGCV Essential Global Change Variable

EHPV Essential Healthy Planet Variables

EOV Essential Ocean Variable

ESDGV Essential SDG Variables

GCI GEOSS Common Infrastructure

GCOS Global Climate Observing System

GEO Group on Earth Observations

GEOSS Global Earth Observation System of Systems

GSTS GEOSS Science and Technology Stakeholder

GSTSN GEOSS Science and Technology Stakeholder Network

IGOS Integrated Global Observing Strategy

IGOS-P Integrated Global Observing Strategy Partnership

IoM Internet of Models

IoT Internet of Things

LKB Living Knowledge Base

MDG Millennium Development Goal

OGC Open Geospatial Consortium

OHI Ocean Health Index

RRR Rolling Repository of Requirements

SBA Societal Benefit Area

SDG Sustainable Development Goal

SEE-IN Socio-Economic and Environmental Information Needs

SoS System of Systems

SOSH Safe Operating Space for Humanity

UNFCCC United Nations Framework Convention on Climate Change

URR User Requirements Registry

VST Virtual Stakeholder Table

WPS Web Processing Service

Executive Summary

This document describes the ConnectinGEO methodology to link societal goals and targets to Essential Variables (EVs) required to monitor progress towards these goals and targets. This goal-based methodology is complementary to the expert-based methodology widely use in scientific and Earth observation communities, including the GEO communities in the Societal Benefit Areas (SBAs), to determine EVs based on current feasibility and impact. To a large extent, the ConnectinGEO methodology is informed by the outcomes of a workshop organized jointly by ConnectinGEO and the GEOSS Science and Technology Stakeholder Network (GSTSN) on "Navigating Sustainability on a Changing Planet," which was held on March 23-25, 2015 in Norfolk, VA, USA.

The Workshop reviewed two key aspects of the future development of the Global Earth Observation System of Systems (GEOSS): the alignment of the efforts to the grand challenges associated with humanity's quest for sustainable development; and the opportunities arising for future Earth observation and information systems. The workshop had contributions from a broad range of Earth Science and observation communities with the aim of stimulating a consensus on alignments and initiatives for GEOSS. For example, among others, the Program Committee included representatives of the GSTSN, the GEO Institutional Development Implementation Board, the GEO Societal Benefits Implementation Board, the GEO Water Cycle community, the World Health Organization, the Belmont Forum, the European Science Foundation, the Earth Science Information Partnership, the European Commission and the ConnectinGEO project.

Workshop participants recognized that food, water and energy security are at risk, as factors of expanding population growth, increasing standards of living and escalating migration are an increasing threat to international stability. Climate change and its impact is a major factor in these trends and there are important thresholds that if crossed may lead to changes in the macro-features of the Earth system. This can be expressed as concern that we could be crossing the global boundaries of the Safe Operating Space for Humanity (SOSH),which in turn, would pose a real threat to achieving sustainable development.

Inspired by the workshop outcomes, a dual approach to monitoring the Earth's environment was proposed by the H2020 ConnectinGEO Project to (1) define Essential Variables (EVs) and (2) understand the way those EVs are linked to societal environmental goals and their specific targets leading to achievement of the goals. A "goal" is defined as "the objective towards which an endeavour (in our case, the societal and environmental sustainability) is directed in the end". The international community is progressing towards new frameworks for promoting sustainable development and these efforts require indicators which are defined here as a group of observations that taken together give an indication of progress towards targets. For this purpose, indicators require the integration of Earth observations with socio-economic data. The motivation is to be able to use EVs and observations to create indicators required to monitor progress towards these goals and targets.

The set of Essential Variables are collectively defined here as "a minimal set of variables that determine the system's state and developments, are crucial for predicting system evolution, and allow us to define metrics that measure the trajectory of the system." This deliverable suggests that there are two basic processes that lead to community-accepted EVs:

- The “expert-based” approach is widely used in scientific and EO communities. The process of defining the set of EVs starts at measurement feasibility and expert insights on impacts and establishes a link to societal benefits in a retrospective way . The EVs for climate derived from the UNFCCC are the most prominent example.
- The “goal-based” approach starts with considering societal and environmental goals, the associated targets, and the indicators established as a report card and planning tool and identifies the EVs required to quantify indicators to measure progress towards the goals.

The expert based approach is the current process used for EV definition in the observation community. The goal-based approach is not used often in defining observational needs. To a large extent, the goal-based approach was informed by the outcomes of the Norfolk workshop. At the workshop, the following societal and environmental goal sets were reviewed: Global Change Monitoring, Global Boundaries for the SOSH, Safe-Guarding the Earth's Life Support System (ELSS) and the Sustainable Development Goals (SDGs). The agreement on each of these specific goal sets and target sets are reached in a consensus built on societal deliberations, most often initiated by international organizations. The corresponding indicators are defined based on input from relevant scientific communities and the observations available or, at least, considered feasible. There are many commonalities between these goal sets because all of them share a common knowledge base and also an objective of planetary sustainability. We propose to look at the common metrics and variables and to define a single common set of EVs for monitoring the planet's System-of-System (SoS) status and trends.

The Group on Earth Observations (GEO) has stimulated initiatives for the coordination of Earth observation networks and the development of existing and new observing systems. Nevertheless, the formal process to EV definition has not been fully integrated into GEO. GEO has been collecting data and information about needs to identify the collection of relevant data and to facilitate the generation of the information and knowledge meeting societal needs. The core question of what needs to be measured and which are the EVs to be captured remains, to some extent, still unanswered.

The development of *blue prints* for establishing the links between indicators and EVs as well as the actual observational requirements for these EVs is recommended. The blueprints should be documented including the relation between the goal and target sets, and the information on indicators and their related EVs. This could be done through a “Knowledge Base” which could then support observational gap analyses to reveal missing information for EVs and indicators; an approach that will be tested in ConnectinGEO and will be described in upcoming deliverables.

Other requirements emerging from the Workshop are the need for a GEOSS implementation that facilitates new data and big data integration and addresses relevant policies and issues, including: open access, privacy, processes to usage monitoring, legal interoperability and quality labelling as a way to ensure trust in EO. To increase accountability, traceability, and attribution; data citation and a consistent digital object identification system should be implemented.

PART 1: THE CONNECTINGEO METHODOLOGY

Abstract

The ConnectinGEO methodology is a goal-based approach to the identification of variables that are essential for the monitoring of progress towards societally agreed-upon goals. The starting point are sets of goals that have been defined in a societal consensus-building deliberation. These goals are associated with targets to be achieved in a defined time interval. Target-specific indicators provide reporting card for progress towards the targets and a management tool for the planning of actions that facilitate reaching the targets. The ConnectinGEO methodology provides the link from these indicators to the essential variables (EVs) that need to be observed in order to quantify the indicators.

The ConnectinGEO methodology is complementary to an expert-based methodology for the identification of EVs. The expert-based methodology is widely used by scientific and Earth observation communities to determine domain or area specific sets of EVs. Examples are the Essential Climate Variables (ECVs), Essential Ocean Variables (EOVs), and Essential Biodiversity Variables (EBVs). Most communities give current feasibility of observing the EVs and cost-effectiveness a high weight, which can result in less feasible but high impact variables being undervalued. In most cases, the link from these sets of EVs to societal benefits and goals is established after the EVs have been agreed upon in the community.

Here we review four existing and candidate goal sets, discuss corresponding targets and describe the indicators that could be used to identify the relevant EVs. The goal sets discussed are related to global change, the global boundaries of the safe operating space for humanity, the safeguarding of the Earth's life support system, and the agreed-upon Sustainable Development Goals.

It is recommended that the blue prints for the linkage between indicators and EVs are implemented in the GEOSS Knowledge Base. This Knowledge Base includes the Socio-Economic and Environment Information Needs (SEE-IN) Knowledge Base, which will contain the blue prints to derive observational requirements for societal goals. It uses this SEE-IN Knowledge Base in an envelop knowledge base for gap analysis by comparison of observational requirements to existing observations, and it supports access to observations from a starting point in societal goals and information needs. The core elements of the GEOSS Knowledge Base are described and recommendations for the implementation are made.

1 Introduction

1.1 Scope of the Report

One of the objectives of the *ConnectinGEO (ConnectinGEO)* project is to facilitate a broader and more accessible knowledge base to support meeting the needs of the users in the *Group on Earth Observations (GEO) Societal Benefit Areas (SBAs)*. A core tangible outcome of the project will be a prioritized list of critical gaps within the European Union in key observations. The underlying concept for the prioritizing is that of *Essential Variables (EVs)* derived from, or linked to, societal goals and benefits (see Section 2.3.

The concept of EVs has been used in a number of Earth observation communities to identify and prioritize variables and observations that are key to the missions of these group. Examples are the *Global Climate Observing System (GCOS)* under the *United Nations Framework Convention on Climate Change (UNFCCC)*, which developed a set of *Essential Climate Variables (ECVs)*. Several ocean communities are engaged in developing sets of *Essential Ocean Variables (EOVs)* for marine, chemical, and physical aspects of the oceans. In the GEO Biodiversity SBA, a discussion is in progress with the goal to identify a set of *Essential Biodiversity Variables (EBVs)*. A review of the current status is provided by the ConnectinGEO D2.2 "EVs current status in different communities and way to move forward." In most cases, all these efforts are based on input from the experts in the relevant field, who identify what

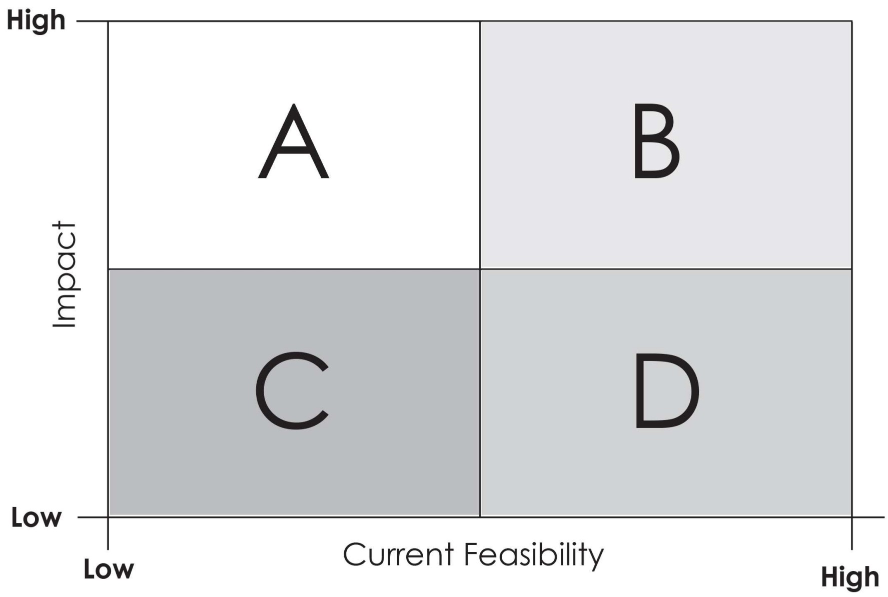


Figure 1. Societal Impacts Versus Feasibility of Observations.

they need and what is feasible to observe. In most cases, a link to the societal benefits is constructed after the EVs have been identified.

This expert-based approach, which gives the current feasibility to observe the variables a high weight, addresses mainly the areas B and D in Fig. 1. In particular, area A could have high societal benefits if research and technological development would increase the feasibility of observing those EVs that are important for area A. Therefore, in the frame of ConnectinGEO, the goal is to add a complementary methodology for the identification of EVs that starts with the societal goals and benefits and gives current feasibility a lower weight. This complementary approach allows for a gap analysis originating in societal goals and comprehensively covering both what is feasible today in terms of observations and what would have high societal impact if it could be made feasible.

As a first step towards the gap analysis, ConnectinGEO formalized the methodology to first translate user knowledge needs linked to well-defined societal goals into indicators and then identify the EVs required to quantify these indicators. Moreover, observation requirements need to be specified for the EVs depending on specific applications. For the gap analysis, these requirements can be compared to information on available observations to identify key gaps.

The first part of this report describes the motivation for the link between societal goals and EVs, and defines the methodology used to establish this link. Much of the contents of this part are derived from the presentations and discussions that took place during the ConnectinGEO SDG Workshop, which was co-organized with a number of international organizations engaged in the *GEOSS Science and Technology Stakeholder Network (GSTSN)* as the 3rd *GEOSS Science and Technology Stakeholder (GSTS)* Workshop "Navigating Sustainability on a Changing Planet." This workshop took place on March 23-25, 2015 in Norfolk, VA, USA and attracted about 55 experts mainly from Europe and North America. The second part of the report contains the Workshop report, including the minutes, of the ConnectinGEO SDG Workshop.

Subsequent to this workshop, another GSTS workshop titled "Concepts, Technologies, Systems and Users of the Next GEOSS" took place at the same venue on March 24-26, 2015. The deliberations at this workshop also impacted the contents of the present report.

The first part of the report defines the strategic goals to be considered in the frame of ConnectinGEO, which are based on the *Sustainable Development Goals (SDGs)*, the concept of planetary boundaries, and considerations of sustainable development. For these goals, indicators that measure progress towards these goals are discussed. Blue prints for the identification of related EVs are developed.

Based on the United Nations' agreement on SDGs, and the scientific understanding of planetary boundaries of the *Safe Operating Space for Humanity (SOSH)*, an integrated list of societal goals is presented. The metrics to measure progress towards the goals are discussed. These metrics are defined by a set of indicators.

The information on goals, associated targets, and the indicators are published in the GEOSS Knowledge base, which is denoted as the *Socio-Economic and Environmental Information Needs (SEE-IN)* Knowledge Base (formerly User Requirements Registry).

The SEE-IN Knowledge Base is described briefly in the report. At the Ministerial Summit on Earth Observations held on January 17, 2014 in Geneva, the ministers provided guidances for the future development of GEO and *Global Earth Observation System of Systems (GEOSS)*. In the guidance document endorsed by the summit, the "*proposed key areas of activity for the next decade are:*

1. *Advocate for the value of Earth observations and the need to continue improving Earth observation worldwide;*
2. *Urge the adoption and implementation of data sharing principles globally;*
3. *Advance the development of the GEOSS information system for the benefit of users;*
4. *Develop a comprehensive interdisciplinary knowledge base defining and documenting observations needed for all disciplines and facilitate availability and accessibility of these observations to user communities; and*
5. *Cultivate global initiatives tailored to meet specific user needs.*"

The activities reported in the current report address key area 4 by defining the processes required to identify and document observations needed based on a comprehensive overview of societal goals. One of the main purposes of the SEE-IN KB is to provide blue prints for the definition of observation needs based on agreed-upon societal goals.

The traditional approach to the definition of observation needs is focused on specifications of variables to be observed and the characteristics of the data to be collected (e.g., spatial and temporal resolution, accuracy, latency, etc.). In most existing databases documenting observation needs, the link to the societal applications that would benefit, or depend on, these observations is often not captured. The GEOSS *User Requirements Registry (URR)* made an effort to derive observational requirements from applications that generate the societal benefits (e.g. Plag et al., 2012a,c, 2013) and from users and their information needs. However, the URR does not provide blue prints for the linkage of information needs to observation requirements. In particular, there is no defined process to derive observation needs from agreed-upon goals.

1.2 Motivation

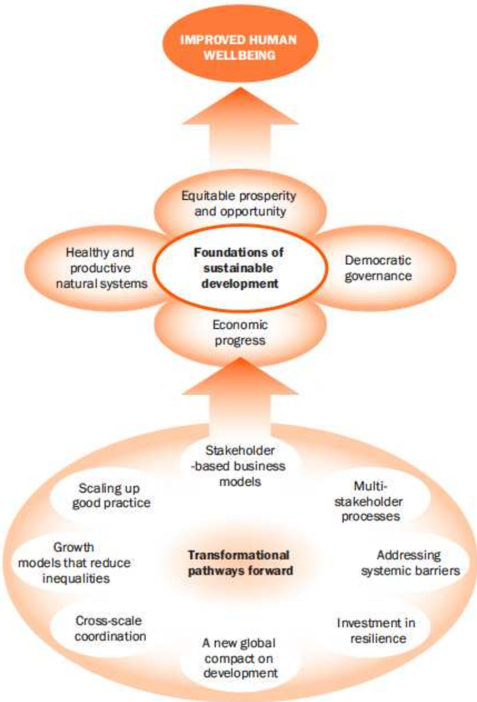
Sustainable development and broad human wellbeing can only be achieved through transformational pathways from the current unsustainable path toward a foundation of a sustainable development (Figure 2). Finding the pathways that would bring us closer to sustainable development is only possible if decision making in all societal sectors can be based on evidence and environmental intelligence. Equally important is that governance can make a transition from "decisions for the people" to "decisions with the people," i.e., a transition towards participatory, informed governance. Informed governance can lead to policies, planning, and codes supporting best practices for sustainable development, i.e., a "development that meets the needs of the present while safeguarding Earth's life-support system, on which the welfare of current and future generations depends" (Griggs et al., 2013). The sustainable development of thriving communities is embedded in local, regional and global processes and developments. Understanding that our civilization developed and can only be sustained within a "safe operating space for humanity" (Rockström et al., 2009a,b; Rockström & Klum, 2015), sustainable thriving communities require that the current rapid changes of our planet do not cross the global boundaries of this safe space. There is mounting evidence that the planet is on a path out of the Holocene, i.e., the epoch in which humanity developed civilizations, into a new epoch "of our making" (e.g., Syvitski, 2012), which may, or may not be the Anthropocene. This transition is inherently non-stationary, posing the scientific problem of anticipating an uncertain future based on knowledge created during a predominately stationary past. The limited foresight challenges mitigation and adaptation to future changes. A transition from discussing uncertainties to understanding the possibilities is necessary. Participatory informed governance can provide a basis for decision making that considers possibilities with broad buy-in from stakeholders.

Participatory governance is important at all levels from local to global. Acknowledging this, particularly for the development of global strategic goals and broad agreements, such as the SDGs and the disaster risk reduction goals, processes that facilitate broad participation have been put in place. Access to comprehensive knowledge bases is crucial for these processes to ensure that participation is informed and deliberations can be evidence-based.

In many cases, focus has been on improving the interface between science and society (see, e.g., Plag, 2012). However, finding the transformational pathways mentioned above seems to require a view of science as an integral part of society, with the scientific knowledge embedded in all decision making. In particular, science needs to be at an equal level with other stakeholders in participatory governance. The co-design and co-creation of practice-relevant knowledge is mandatory for the transition to knowledge-based decision making and informed, participatory governance. In many cases, a co-usage of the knowledge is required, engaging science in enabling a wide range of stakeholders in the use of the knowledge created.

At its most basic level, participation and engagement are a way of ensuring that decisions are made after those affected by the decisions were able to dialogue with those making the decisions (Creighton, 1980). "Authentic public participation" (King et al., 1998) requires involving stakeholders in "dialectical exchange" (Fischer, 1993) or discourse (Fox & Miller, 1995), facilitating an examination of stakeholders interests, working together with them to arrive at decisions, and engaging them in open and authentic deliberation. Thus, the public must be allowed to discuss potential solutions to a problem and then allowed to choose from among them. Many public hearings fail to generate public acceptance when the public has little chance to enter the decision-making process.

Crucial to effective public participation is the provision of relevant information (Creighton, 2005; Crosby et al., 1986). This is even more true in the context of evidence-based decision making on science-based issues. Participation and engagement offer a venue for educating stakeholders about contentious or poorly understood issues (Burby, 2003; Thomas, 1995; Walsh, 1997); this requires providing stakeholders with accurate, relevant, and accessible (in organization and content) information to facilitate informed participation (Connor, 1988; Thomas, 1995). This information aids stakeholders in developing the needed capacity for participation and levels the playing field between stakeholders and government actors (Stern



From		To
Development assistance	→	A universal global compact
Top-down decision making	→	Multi-stakeholder decision-making processes
Growth models that increase inequality and risk	→	Growth models that decrease inequality and risk
Shareholder value business models	→	Stakeholder value business models
Meeting "easy" development targets	→	Tackling systemic barriers to progress
Damage control	→	Investing in resilience
Concepts and testing	→	Scaled up interventions
Multiple discrete actions	→	Cross-scale coordination

Figure 2. Pathways to Sustainability. *Sustainable development requires transformational pathways forward to a sound foundation of sustainable development. Most of the transformations depend on access to comprehensive knowledge bases and participation of stakeholders in the creation of knowledge and the processes that lead to decisions. From IRF2015 (2013).*

& Fineberg, 1996). "It is the information content that appears to tip the balance, creating more knowledgeable public deliberation, and ultimately greater support for tough decisions" (O'Connell & Yusuf, 2011, p. 187). Yet, much of the research has focused extensively on means of providing information (e.g., newspaper, radio, public meetings, etc.) but has neglected the content and structure of the information. Similarly, many efforts in GEO have focused on the means to share data and information and less on the actual contents.

Most of the transformations depicted in Fig. 2 depend on access to comprehensive knowledge bases and participation of stakeholders in the creation of knowledge and the processes that lead to decisions. This requires the integration of data and practice-relevant knowledge with tools that are able to respond to information needs arising in stakeholder deliberations.

The rapid progress in computation and communication technologies allows for new virtual forms of participation in governance and for a linkage between stakeholders and a broad knowledge base that gives access to a wide range of environmental intelligence. A cyberinfrastructure that could facilitate this is a *Virtual Stakeholder Table (VST)* that enables broad participation of stakeholders in deliberations and facilitates a democratizing of knowledge (Plag, 2012). The underlying *Living Knowledge Base (LKB)* would combine integrated environmental, social, and economic data from traditional sensors, human sensors, and models that can generate the information requested by stakeholders for their deliberations, as well as the knowledge created in the deliberations.

Earth observation consisting of in situ, airborne and spaceborne instrument sensors provide rapidly increasing environmental data, and at local to international levels, efforts are made to use the observations to create environmental intelligence. Socio-economic data from many traditional sources also are increasingly available. The rapid proliferation of electronic media has led to an explosion of data: every day, 2.5 quintillion bytes of data are created. These data come from, for example, digital pictures, videos, intelligent sensors, posts to social media sites, purchase transaction records, cell phone GPS signals, etc. There is a great interest both in commercial and research communities around this Big Data. "Analyzing Big Data will become a key basis of competition, underpinning new waves of productivity growth, innovation, and consumer surplus" (Manyika et al., 2011). The use of Big Data for solving social problems and supporting sustainable development is still in its advent.

Despite the rapidly increasing data availability, the data gap identified in the Agenda 21 (United Nations Sustainable Development, 1992) still exists, and information derived from data often does not meet the information needs of societal users. At Rio+20, co-design of research agendas and co-creation of knowledge were identified as necessities to better integrate science and society in an effort to inform sustainable development (e.g., Copernicus Alliance, 2012). There is a necessity "to commit to transdisciplinary and thus integrated processes of co-designing research agendas and to co-producing knowledge with researchers, decision makers and stakeholders for addressing challenges for global sustainability and developing possible solutions" (Mauser et al., 2013). Importantly, co-design and co-creation of knowledge is still not sufficient: in many cases, societal users need support in applying the knowledge to practical problems and a co-usage of the knowledge needs to complete the loop of knowledge creation and application. Moreover, the knowledge usage itself has to feed back into the process of co-design and co-creation as a basis for a living knowledge base. The co-design, co-creation and co-usage of knowledge require integration at several levels. Cyber-infrastructure can support this integration if it links the creation of knowledge to the use and the researchers to the societal stakeholders.

Informed governance is central to sustainable development and hinges on evidence-based decision-making. Co-design, co-creation, and co-usage of practice-relevant knowledge are necessary conditions to achieve this, and the importance of co-design of research agendas and co-creation of knowledge has been underlined recently (e.g., Copernicus Alliance, 2012; Mauser et al., 2013). Conceptual development is needed for sustained approaches to this cooperation of academia, research and societal stakeholders. Research programs addressing fundamental challenges to sustainability, such as "Future Earth," depend on academia responding to this challenge (Mauser et al., 2013). There is also an urgent need to develop adaptation science (Moss et al., 2013) to inform sustainable development on a planet that is in a transition out of the Holocene. The rich portfolio of assessment of expected impacts of climate change requires a particular focus on practice-relevant knowledge supporting adaptation in the complex socio-economic environment of a global civilization. Likewise, infrastructure that would facilitate and support this cooperation is not available for practical use.

A better understanding of how rapidly increasing data volumes, modeling capabilities, and computational capacity can be utilized to aid co-design, co-creation and co-usage of knowledge, and support decision making for sustainable development of communities. There is a fundamental need for data integration across boundaries between instrumental sensors, model-generated data, traditional socio-economic data, emerging big data, and future information from the emerging *Internet of Things (IoT)* and a possible *Internet of Models (IoM)*. The opportunities that are in the emerging "data supernova," the rapid development of computational resources, and the emergence of new human-based data sources can be utilized to generate the knowledge need to achieve overarching goals such as the emerging SDGs. The increasingly rapid succession of technological revolutions necessitates the development of concepts and approaches not for the technology of today but for that of tomorrow. By aiming at data integration that accommodates anticipated technological revolutions (such as the IoT and IoM) and a continued proliferation of big-data mining and analysis, the ground can be prepared to utilize the wealth of information for the creation of practice-relevant knowledge in support of sustainable development.

1.3 The Contribution of GEOSS

From the onset, GEOSS was intended to integrate Earth observations, socio-economic data and Earth system models to provide decision support for policy and management decisions (Fig. 3 and GEO, 2005b).

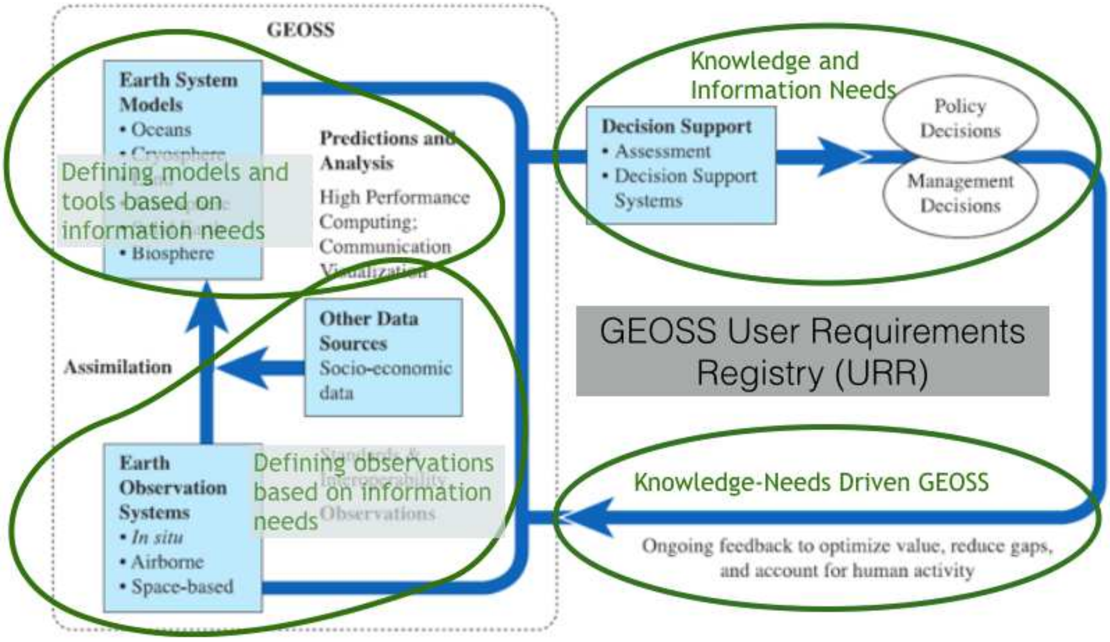


Figure 3. GEOSS and Societal Information Needs.
In the reference document (GEO, 2005b) accompanying the Ten-Year Implementation Plan for GEOSS (GEO, 2005a), observations provided by GEOSS were to be combined with socio-economic data and models to generate information needed by users However, the main focus of GEOSS has been on sharing data and establishing services base on EOs. It will be important to adjust GEOSS to meet knowledge needs by combining EOs and socioeconomic data with models. Modified from GEO (2005b).

This has not changed, and the Ministerial Summits held after 2005 have reconf rmed this overarching conceptual goal for GEOSS. The focus on the global and regional sustainable development goals during the most recent summit conf rms this concept. Consequently, GEOSS needs to focus on the integration of Earth observation with socio-economic data (from the "human observatory" discussed during the 2012 Workshop in Bonn, see Plag, 2012) and the assimilation of Earth observations and other data into models that can provide answers to the questions that decision makers might have.

Fig. 3 provides a clear structure that connects data through models to knowledge. GEOSS up to now has been focused on a part of the data, i.e., the Earth observation data, while other data (social data, crowd-sourcing, and economic data) as well as Earth system models have not be integrated. As a result, most of the links between observations and the knowledge needs of decision making have been limited to improved data delivery, visualization, and narrow domain models. It will be important to make progress towards the original vision of GEOSS as a *System of Systems (SoS)* that links data through models to societal knowledge needs and societal benef ts. This requires a GEOSS that is responding to knowledge and information needs and def nes observations and modeling tools based on these knowledge and information needs (Fig. 3). The URR developed for GEOSS needs to be replaced by a more comprehensive knowledge base.

To achieve this, it is crucial to have a clear picture of the knowledge needs of decision makers at all levels. These information needs inherently are connected to information about the state, trends and future trajectories of the Earth system. The metrics required to measure progress towards agreed-upon goals depends on the availability of socio-economic and environmental observations. This underlines the importance of the fourth key area of activity listed in the guidance document endorsed at the 2014

Summit. The observation needed to quantify progress towards agreed-upon goals as well as those needed to facilitate this progress are the ones that have a high priority in the development of GEOSS. Therefore, GEO is in need of a process that can link the overarching goals, the specific agreed-upon targets, and the indicators that measure progress to the EVs that need to be observed. Here we therefore extent the fourth key area of activity to a knowledge base that defines and documents observations needed to a knowledge base that includes the sets of goals, targets and metrics that makes these observations essential. The outcome of this extended activity could provide valuable guidance for GEO in identifying priorities for observations.

2 Defining Information and Observation Needs

2.1 Observation Needs: State of the Art

There are a number of databases that register observation needs. Common to all of these databases is a separation of the process that identifies the observation needs from the documentation of these needs in the registries. Likewise, most of the databases focus solely on the question of "What is needed?" As a result, the registries contain specifications of observation needs in terms of variables, their spatial and temporal resolution and coverage, as well as other attributes such as accuracy and latency. Some databases also provide information on observing technologies. Most databases do not provide information on the question of "Why is it needed?" or "Who needs it?" The links between the observation specifications and applications that depend on the observations are normally not documented, and information on the users that benefit from the observations and the applications is not collected. Most existing databases are focusing on specific domains, while very few have a global scope.

In principle, the existing databases could be utilized in gap analyses by comparing the documented needs to the available observations that are, for example, discoverable through the GEOSS *Discovery and Access Broker (DAB)*. However, the lack of information on the links between observations and their benefits that result from them being used strongly reduces the value of the existing databases for prioritization of gaps and existing observations.

An exception is the URR, which aims to fully document the users, their applications, and the resulting observation needs in all GEO SBAs (Plag et al., 2010). The basic questions the URR address are "Who are the users?" "What are they doing?" and "What do they need to do what they are doing?" Moreover, the URR collects information on the societal benefits associated with applications and therefore supports at a low level prioritization (Plag et al., 2012a).

Most of the existing registries of observation specifications are limited in scope, usage, and services. In particular, they do not integrating knowledge creation in the sense that societal goals could be linked to observational requirements. Moreover, the access means available for the existing registries do not support deliberations on what is needed and why. They also are not integrated with the means that support discovery and provide access to data. The URR has very simple means for deliberations. A connection with the GEOSS DAB is feasible and could support the chain from information and knowledge needs to data discovery and access.

There is a need for a more elaborated approach to the identification of observation requirements that truly can help to meet the information and knowledge needs, and the connection from the information and knowledge needs to data. This is the rational for the development of the GEOSS Knowledge Base.

2.2 The GEOSS Knowledge Base

2.2.1 Ministerial Guidance

The Ministerial Guidance identif es focus area 4 as: "*Develop a comprehensive interdisciplinary knowledge base defining and documenting observations needed for all disciplines and facilitate availability and accessibility of these observations to user communities*." Responding to this guidance requires a thorough analysis of the text.

First, we have to ask, what is a comprehensive interdisciplinary knowledge base? In a more general sense, a knowledge base is a collection of facts and rules for problem solving (Heritage, 2000). In a more narrow sense it is used in Computer Science to denote the part of an expert system that contains the facts and rules needed to solve a problem. A knowledge base is far more than a (relational) database since it includes rules to derive new knowledge and solve a problem. The adjective "comprehensive" implies that the knowledge base covers basically the global needs. Likewise, the adjective "interdisciplinary" requires a more or less transdisciplinary approach with a comprehensive ontology that could be provided through the semantic Web. In summary, the guidance seems to ask for a knowledge base with (1) all the relevant facts for all disciplines; (2) well-def ned rules how to use the facts to derive observations needed; (3) and *inference engine* that can derive the observation requirements based on these rules.

The guidance aims for a knowledge base "... def ning and documenting observations needed for all disciplines." With respec to "needed for all disciplines", we have to asked what is it, the disciplines want to do or achieve that creates the need. **What are the goals that the observations are needed for?**

2.2.2 Purpose and Goals of the GEOSS Knowledge Base

A core function of the GEOSS Knowledge Base is to facilitate the linkage between societal goals and targets to EVs. The targets are connected to indicators that are report cards for the progress towards the targets and planning tool for measures to achieve the targets. EVs need to be monitored in order to allow a quantif cation of the indicators.

The primary goals of the GEOSS Knowledge Base include:

- capture the socio-economic and environmental knowledge needs of a wide range of societal stakeholders;
- link societal goals and targets to essential variables and observational requirements;
- use the value chains from observations to end users to facilitate access and improve applicability of EO data and products;
- enable gap analyses and prioritization;
- support the identif cation of EVs and document the EVs.

The implementation of the goal-based approach to EVs (see Section 2.3.2) is based a general "Blue Print":

- For each set of goals, targets can be agreed on
- For targets, metrics based on indicators can be developed

- For indicators, "essential variables" needed to quantify the indicators can be identified

For the expert-based approach, different Blue Prints have to be developed.

2.3 Essential Variables

2.3.1 Introducing the EV Concept

Propelled by technological progress and efforts for data sharing, significant progress has been made in ensuring that *Earth Observations (EOs)* are collected and available to comprehensively meet societal information needs. However, there are still many information needs that cannot be met based on the observations collected and shared. Besides technological obstacles and sometime inadequate financial resources, a key obstacle is the lack of a general consensus on what variables are essential to monitor in order to ensure informed decisions. Different communities promote those measurements that they deem beneficial for their cause. Groups planning and conducting programs to collect EOs would benefit from the existence of a set of commonly agreed variables as a basis to prioritize and commit resources and to support progress towards an evidence-based knowledge base for decision making. EO gaps still remain and many key variables central to scientific and societal information needs are not, or not sufficiently observed. In particular, only a few GEO SBAs and themes have agreed, or have made significant progress towards agreement, on a specific set of variables to be observed.

The concept of EVs is an approach to identify priorities for EO efforts. For any given subject area, the EVs are those variables for which observation requirements need to be specified and efforts need to be made to provide observations meeting these requirements.

The concept of EVs assumes that there is a (small) number of variables that are essential to characterize the state and trends in a system without losing significant information. It is that set of variables that needs to be observed if past changes in the system have to be documented and if predictability of future changes is to be developed. Identifying this set of EVs allows for a commitment of inherently scarce resources to the essential observation needs. It also supports and eases the management of data and observations all along the chain from the measurement of raw data, through the processing and to the delivery of products, information and services needed by end users.

Many applications are supported by knowledge of the relevant EVs:

- Describing the processes in any of the coupled socio-economic and environmental SoS at physical, biogeochemical and biological level.
- Monitoring the state and trends in these systems in different domains and attributing the trends to drivers.
- Predicting the range of "plausible trajectory" of the complex coupled socio-economic and environmental Earth SoS.
- Assessing the risks and threats associated with the detected and predicted changes in the SoS.
- Identifying tolerable boundaries for the trajectories (sustainable development and planetary boundaries).

Table 1. Concept of Essential Variables.

Definition	A set of Essential Variables EVs is a minimal set of variables that determine the system's state and developments, are crucial for predicting system evolution, and allow us to define metrics that measure the trajectory of the system.
Why do we want to know EVs?	– to make sure we know what to measure: prioritizing – to make sure we measure what is needed: gap analysis
How do we identify set of EVs?	**Expert-based**: Based on community objectives, expertise and capabilities, a community agrees on a set of variables that is essential for this community; **Goal-based**: Starting from agreed-upon societal goals, a process leads to targets and metrics to monitor and predict progress towards the targets, and from there to variables required to quantify the metrics, which is mostly defined through a set of indicators.

2.3.2 Definition of EVs

To get a meaningful definition of EVs, it is helpful to clarify the meaning of the terms "essential" and "variable". The adjective "essential" has a number of different meanings, ranging from absolutely necessary and indispensable to containing an essence of something. A variable that significantly improves the reliability and accuracy of the desired results can be considered essential. A variable that provides important information related to a specific goal is essential for those having defined this goal and monitoring progress towards the goal, independent of the capability to actually observe the variable. To what extent a variable is essential for a community or user group (science, policy, etc.) also depends on their information needs.

In order to capture the flexible nature of EVs, in the context of ConnectinGEO the definition given in Table 1 is used. The concept of "variable" embedded in this definition has a certain level of abstraction. Identifying a variable does not imply that observation requirements in terms of spatial and temporal resolution, accuracy, latency, observation interval, etc. are also specified. Nor does it imply that measurement instruments are available to observe the variable. In some cases, variable may not be observable directly and have to be derived from a combination of observations. In such cases, the essential variable may have to be composed of a set of sub-variables that together provide the required information.

In some cases, available observations of an EV may not be ready for use for a specific applications. A lack of sufficient observations of EVs implies limited predictive capabilities and limited means to measure the system's trajectory. The generic nature of the EV definition given in Table 1 allows for the identification of sets of EVs adapted to whatever system or sets of goals is being considered. It also provides for a broad application across different communities, and can be complemented with specific requirements that each community may have. Moreover, in a SoS approach, sets of EVs can be aggregated into larger sets supporting prioritization of efforts across community and system boundaries.

There are two basic approaches to the process that leads to community-accepted EVs (Table 1):

- the "expert-based" approach widely used in scientific and EO communities starts at feasibility and expert preferences and establishes a link to societal benefits in a retrospective way;
- the "goal-based" approach starts at societal goals, the associated targets, and the indicators established as report card and planning tool and identifies the EVs required to quantify the indicators.

As mentioned in Section 1.1, sets of EVs have also been identified based on, for example, United Nations

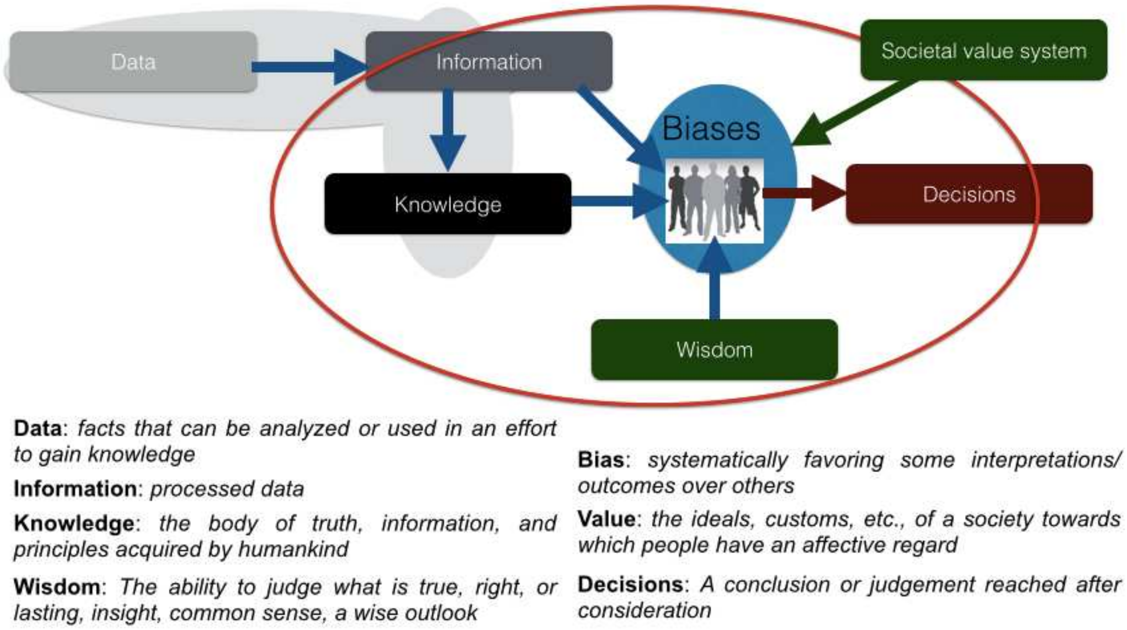


Figure 4. Linking Data and Information to Decision Making.

Conventions. The prime examples are the ECVs derived from the UNFCCC. The approach to these ECVs is more expert-based and based on input from the relevant community. Similar expert-based processes are under way for EBVs and EOVs.

In the frame of GEO, the concept of EVs can be applied to focus the efforts on a smaller set of variables characterizing one or (possibly) more GEO SBAs on global scale. An aggregation of the sets of EVs identif ed in SBAs and *Community of Practices (CoPs)* would promote collaboration among different GEO communities by emphasizing the needs for common EVs.

3 Linking Societal Goals to Observation Needs

3.1 Data, Information, and Decision Making

In GEO, a considerable effort has been on linking data to information that can inform decisions (Fig. 4). Considerable effort has been on the infrastructure and the form for this linkage between existing data and EOs collected and societal decisions that could benef t from these EOs. The expert-based approach to EVs is part of this effort. What has not been in the center of efforts is how decision processes in society make use of information and knowledge and what knowledge is taken into account in decisions that are inf uenced by cultural biases, individual and community wisdom, and the underlying value system of a community.

In ConnectinGEO, the complementary goal-based approach starts at the community level and the goals and targets the community has agreed to reach (Fig. 5). Implicitly, this takes into account the value system, wisdon, and biases that impacted the choice of the goals and targets. Moreover, the effort is less on the means to deliver the data, information, and knowledge but rather on the contents to be delivered to meet the societal needs.

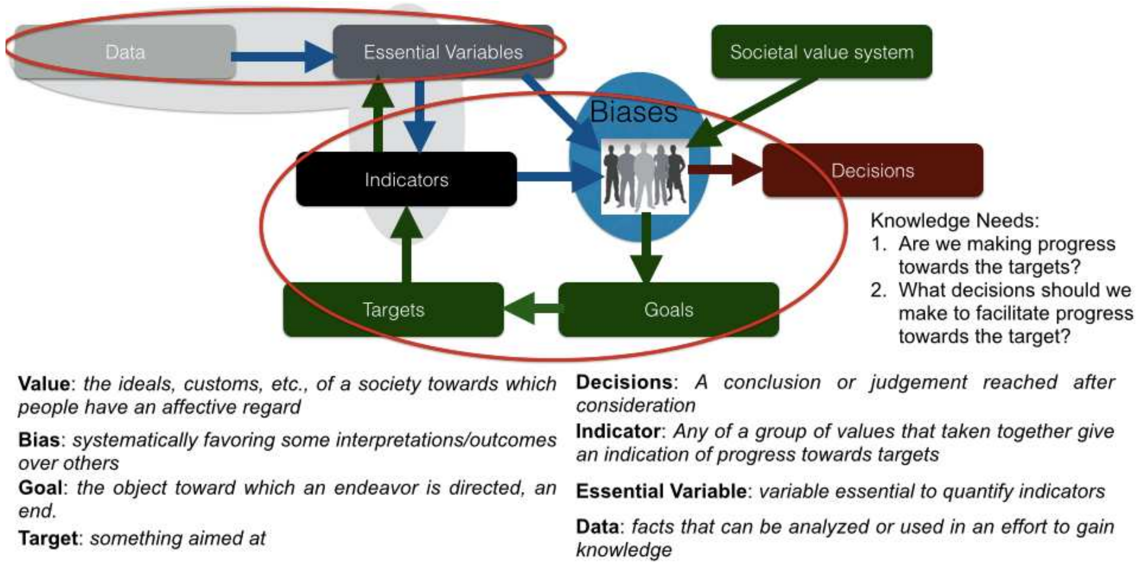


Figure 5. Linking Societal Goals to Data.

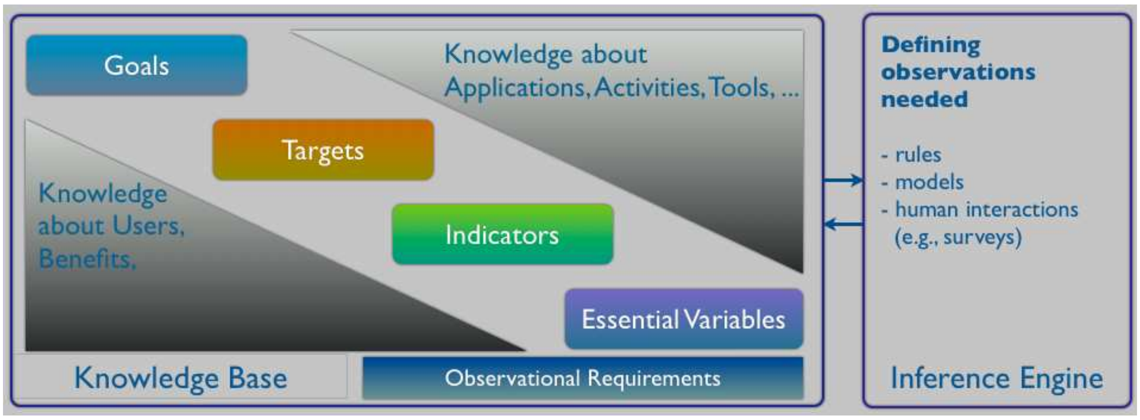


Figure 6. Generic Goal-Based Approach for EV Identif cation.

The goal-based approach assumes the existence of agreed-upon goals and targets as a starting point, and a set of indicators that can be used both as reporting card for progress towards the targets and a planning tool for measures to make progress. The knowledge base has rules and models to link the indicators to those variables that need to be observed in order to quantify the indicators, and an inference engine that can deduce these variables from the indicators.

3.2 Generic Goal-Based Approach

The generic goal-based approach to the identif cation of EVs that correspond to societal goals is depicted in Fig.6. In order to implement this generic approach, knowledge is needed about applications, activities and tools to quantify the indicators and to assess the progress towards the targets. Rules are required to derive the EVs that need to be observed in order to quantify the indicators. In the expert-based based approach, these rules are to some extent ad hoc and community determined. Many communities use deliberations without well-def ned rules. For the goal-based approach, rules could be based on sensitivity studies that reveal to what extent the quantif cation of indicators is impacted by certain variables. In most cases, the tools used to quantify the indicators can be used to develop the set of rules to identify the required variables. In some cases, human interactions will be required, for example, in form of surveys or community deliberations. Knowledge of the users associated with the targets and goals as well as the societal benefits can further support the identification of the EVs.

For GEO, it is of importance to make an explicit choice of the agreed-upon societal goals, for which the associated observational requirements should be prioritized. This will allow a focused efforts on meeting the observational and information requirements for societal goals of high relevance, while not excluding other goals established e.g. in scientific communities, that can benefit from the observations and information provided by GEOSS. In the next Section, we provide a review of examples of societal goals that are candidates for being selected for a focus in GEO. Following the guidance of the Ministerial Summit in 2014, the SDGs are one of the examples considered.

4 Selecting Priority Societal Goals: A Review

4.1 Goal Groups

Community goals can be very different, depending on the societal area the community is embedded. If we are considering scientific disciplines, a common goal is to create new knowledge, for example, by monitoring the environment, assessing the state and trends of the Earth system, and improving our capabilities to predict future states and trends. For social disciplines, the goal may be to enable sustainable development. The Ministerial Summit on Earth Observations in 2014 indicated that the SDGs are goals highly valued by the ministers.

As mentioned in the introduction, Griggs et al. (2013) proposed a new definition of sustainable development, which implies the safeguarding of the Earth's life-support system. With this goal in mind, a set of planetary health indicators could be part of a sustainable development metrics, and observation requirements could be derived from these indicators. The notion of the presents being a transition to a new geological epoch would provide a basis for a global change metrics based on global change indicators. Other goals could be derived from a goal to remain within the global boundaries of a SOSH (Rockström et al., 2009a). In this case, global boundary indicators would provide a metrics and a basis to identify variables that are needed to quantify these indicators. In all these cases, the approach is a goal-based approach starting with goals at the highest level (Figure 6). Progress towards these goals is defined through a set of targets, and measured through indicators. The indicators are used to identify a set of EVs needed to quantify the indicators.

In the following, four specific goal sets are discussed in detail. These goal sets are the focus of ConnectinGEO and are used as examples to populate the SEE-IN Knowledge Base.

4.2 Documenting Global Change

The Holocene, the last geological epoch that began 11,700 years ago, has been exceptionally stable in terms of climate. The paleo-record of climate-relevant parameters for the last 800,000 years does not show any other prolonged period of comparable stability. Changes in all climate-relevant variables were small and the global climate system exhibited small variations around a mean state (Fig. 7). As a result, around 6,500 years ago, sea level also became exceptionally stable allowing humans to establish permanent settlements in coastal river deltas. In these areas, they were benefiting from abundant ecosystem services and logistical advantages.

During the last two centuries this started to change. With increasing access to abundant energy, humanity

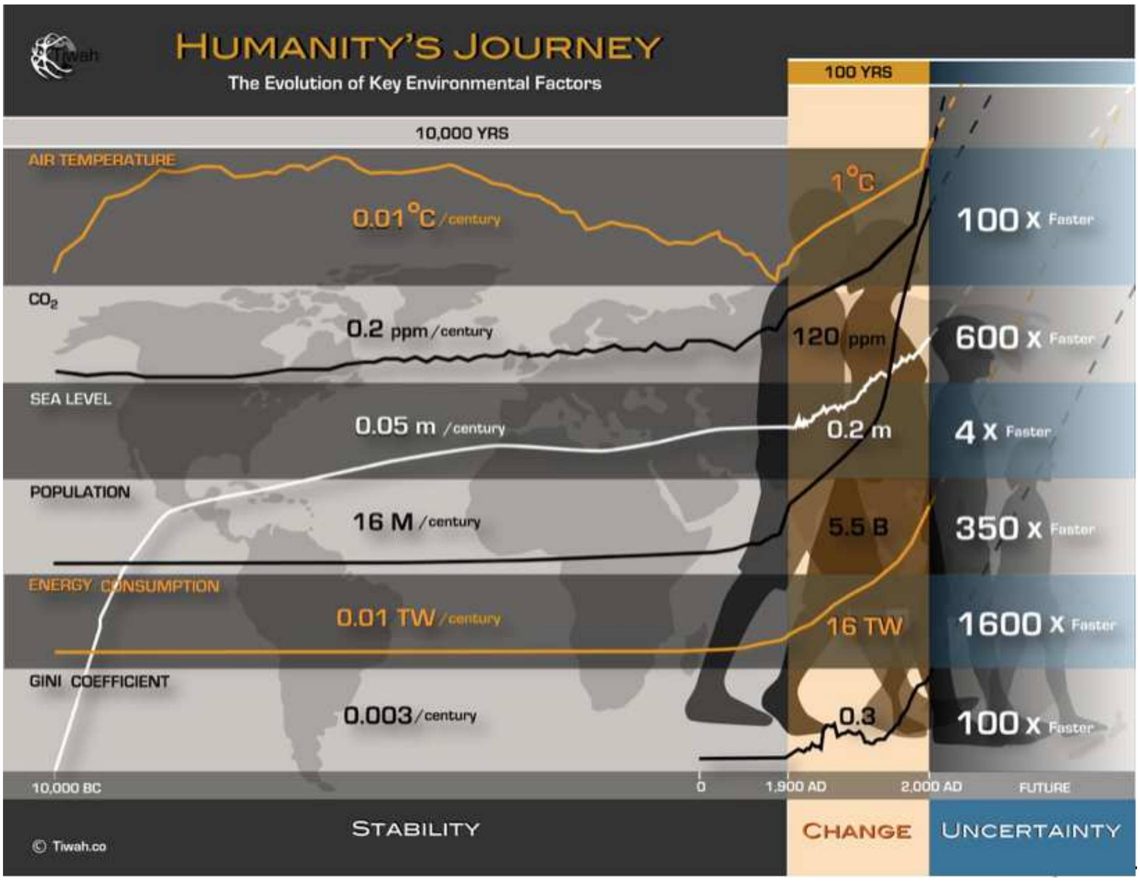


Figure 7. Humanity's journey into the Post-Holocene.
Changes in variables characterizing humanity and climate have increased in the last century dramatically compared to the average per-century changes throughout the Holocene. The speed of anthropogenic global change is accelerating and requires careful documentation and monitoring in order for current and future generations to understand the changes and impacts.

was able to change the surface of the planet as well as core mass cycles significantly and at an increasing speed. As shown in Fig. 7, the changes during the last century were orders of magnitudes larger than the average per-century changes throughout the Holocene. In particular, global energy usage increased dramatically, which allowed humanity to complete change the Nitrogen and Phosphorous cycle in order to sustain a population growth exceeding the pre-1900 average by two orders of magnitude.

Considering the planet with humanity as a complex SoS, the Holocene prior to roughly 1900 appears to have been in a state of homeostasis with small variations around a dynamical equilibrium. In a phase space, this corresponds to a valley keeping the system close to the lowest point in this valley. The anthropogenic mobilization of energy, which comes with an enormous dissipation of energy from the solid Earth (in form of fossil fuels) into the anthroposphere and from there back into the climate system, has pushed the SoS from the valley towards a ridge in the phase space and dramatically reduced the predictability of the state of the SoS (Nicolis & Prigogine, 1977).

Another way to look at the anthropogenic global change is to compare the present state of the SoS with a baseline for system variability during a much longer period. Fig. 8 uses paleo-data for the last 800,000 years to derive the baseline for a number of relevant system variables. For most of these variables, the current value is significantly outside of the normal range during the 800,000 years (e.g., carbon dioxide

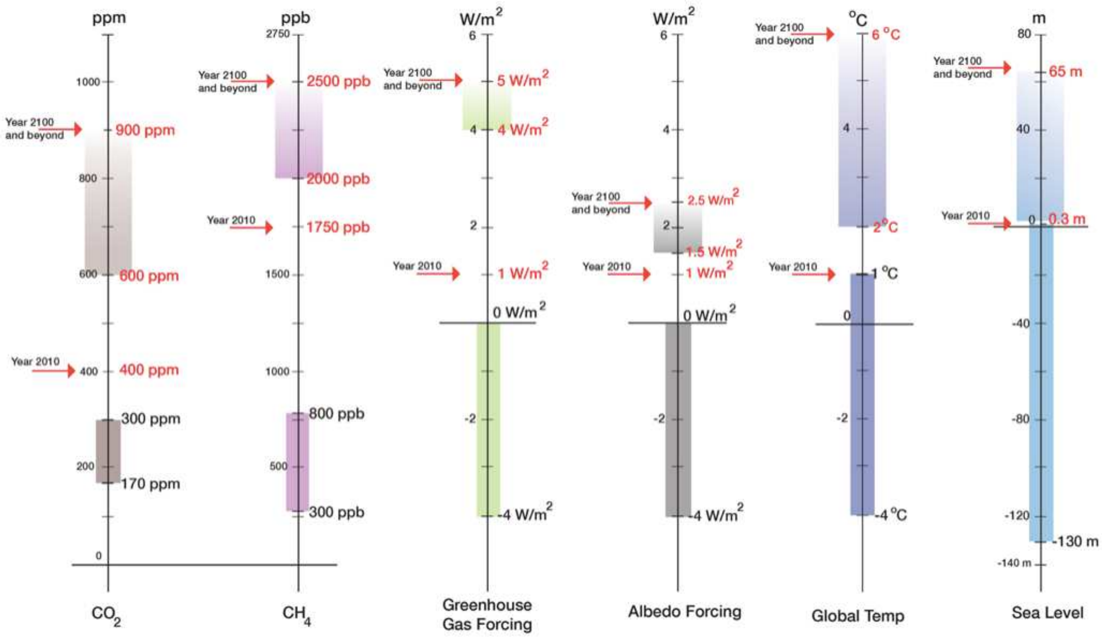


Figure 8. Baseline, Current State, and Prognosis for key EGCVs.
On each axis, the lower boxes indicate the range of variability of of the variable during the last 800,000. The values in the middle denote the 2010 value of the variable, and the upper boxes are the estimated values for 2100 and beyond. Note that in particular sea level may take several thousand years to reach an equilibrium with current and future values of atmospheric carbon dioxide.

and methane), while others are lagging behind (e.g., air temperature and sea level). This has introduced a large disequilibrium that could lead to rapid dynamic responses. Understanding the tipping points and detecting early when the system is approach them is crucial (e.g. Lenton, 2011, 2014). In order to discover the onset of changes in the macro-features of the SoS, detailed and continuous monitoring of the *Essential Global Change Variables (EGCVs)* is needed.

Of particular concern is the fact that the land-based ice masses are in extreme disequilibrium with atmospheric CO_2 and the expected global temperature. The total base line ranges of 130 ppm in atmospheric CO_2 and 5°C in air temperature correspond to a range of 130 m in global sea level (Fig. 8). Even is these relationships cannot be extrapolated linearly to higher values, it is very likely that the equilibrium state of an atmospheric CO_2 content of 100 ppm or more and a temperature increase of 2°C and more is a more or less ice-free planet with a global sea level being 65 m higher than today. The paleo records show that the time reaching this state are most likely several thousand years with the possibility of large melt water pulses in between.

The societal and scientif c goals concerning the ongoing anthropogenic global change could be to

- document the changes that are taking place;
- support attribution of the changes to causes;
- discover emerging trends that could lead to global threats;
- attempt to characterize when we get into a danger zone and need to pay more attention.

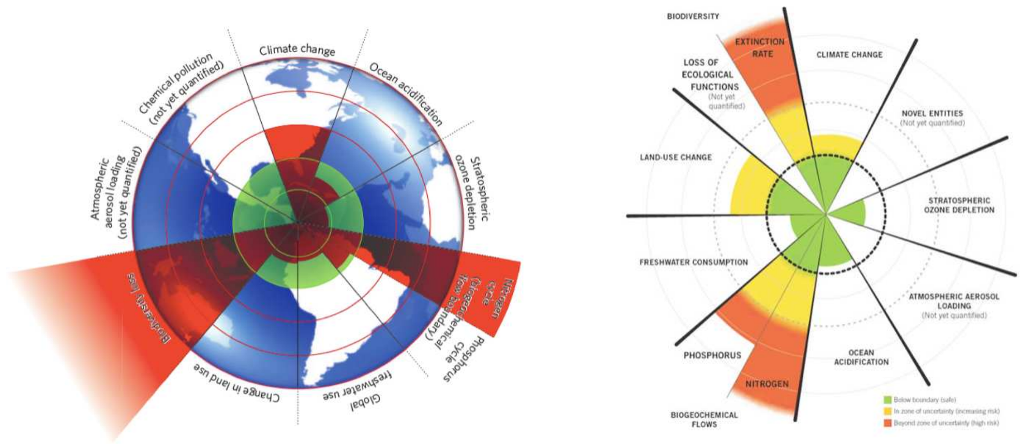


Figure 9. The Global Boundaries of the SOSH.
The left diagram is from Rockström et al. (2009a) and the left diagram from Rockström & Klum (2015). Note that in the more recent diagram, the boundaries that are critically exceeded are the ones for extinction rate and the Nitrogen and Phosphorous cycles. Climate change is in the zone of uncertainty with increasing risk.

Having these goals, the associated targets could be formulated in terms of assessments to be carried out at a regular interval. The assessments would focus on "state-of-the-system" reports. The relevant indicators would have to be designed to fully characterize the state of the complete SoS. The essential variables needed to quantify the indicators, the EGCVs, are the state variables in each of the systems in the SoS. The EOs data base resulting from the monitoring would constitute both an archive for future use and the basis for the frequently repeated assessments of the system state.

It should be mentioned here that the *Integrated Global Observing Strategy (IGOS)* developed by *Integrated Global Observing Strategy Partnership (IGOS-P)* in the decade from 1996 to 2006 in principle had the goals listed above (e.g. Dahl, 1998; Barrie & the IGACO Writing Team, 2004; Lawford & the Water Theme Team, 2004; Marsh & the Geohazards Theme Team, 2004; Plag, 2007). The main objective of the IGOS was to ensure that all essential variables were monitored, which very well translates into the overarching objective of GEOSS.

4.3 Maintaining the Safe Operating Space for Humanity

Rockström et al. (2009a) pointed out that the Holocene was a SOSH and identif ed nine global boundaries def ning this SOSH (Fig. 9). They were able to quantify seven of those boundaries, and discussed that the boundaries for biodiversity loss, Nitrogen and Phosphorus cycle, and climate change had crossed the boundaries (Fig. 9 left diagram). In a reassessment, Rockström & Klum (2015) found that the most important crossings of boundaries were for the extinction rate and the Nitrogen and Phosphorus cycle, while land use changes and climate change were in zones of uncertainty with increasing risk.

Related to these global boundaries of the SOSH, societal goals could be to avoid crossing the boundaries and aiming to stay inside the SOSH. Associated targets could be to make progress to back into the SOSH where boundaries are crossed and to move away from the zone of uncertainty where the quantities are in that zone. In order to monitor progress, boundary indicators would have to be established and quantif ed at regular intervals. In order to allow for identif cation of the underlying processes, it would be important to have regional and global indicators. Those variables needed to quantify the indicators would be the

Figure 10. Society embedded in Earth's Life Support System.
The link between society and the Earth's life support system is economy. The figure was stimulated by a similar figure in Griggs et al. (2013), which placed economy symbolized by coins inside of society. From http://www.economy4humnaity.org.

Essential Global Boundary Variables (EGBVs).

The indicators for global boundaries would constitute the instruments in the planetary cockpit providing the information needed by the planetary pilots, the decision makers, to keep the planet on a safe trajectory inside of the SOSH.

4.4 Safe-Guarding the Earth's Life Support System

The revised definition of sustainable development by Griggs et al. (2013) introduces the concept of the *Earth's life support system (ELSS)*, on which the current and future generations depend, and state that sustainable development is one which provides for our needs while safeguarding the ELSS. Considering that basically all links between society and the ELSS are economic in nature (Fig. 10), it becomes clear that in a sustainable development, economy inherently must have the goal to safeguard the ELSS, besides meeting our needs.

Taking this viewpoint, a societal goal connected to sustainable development could be to ensure that the ELSS is safeguarded. Targets associated with this goal could be established based on subsystems of the

Figure 11. The Agreed-Upon seventeen SDGs of the United Nations.
From hhttps://sustainabledevelopment.un.org/sdgs.

ELSS, including oceans, air, water cycle, ecosystems, forests, etc. Indicators would provide the metrics to measure to what extent the functions of these subsystems in the ELSS are maintained and safeguarded.

The indicators basically constitute health indicators for the various subsystems. An example of already existing indicators of this type are those that make up the *Ocean Health Index (OHI)*. The Ocean Health Index is a comprehensive framework used to measure ocean health from global to local scales (see e.g. http://www.oceanhealthindex.org/), where ocean health is linked to the function of the the ocean to sustainably deliver a range of benef ts to people now and in the future.

After having identif ed the ELSS indicators, a set of *Essential Healthy Planet Variabless (EHPVs)* could be identif ed. These EVs would provide a means to prioritize those EOs that are linked to sustainable development.

4.5 The Sustainable Development Goals

The SDGs have been accepted by the United Nations in late 2015 as the global goal set for the period of 2016 to 2030 (United Nations, 2015). These goals guide the continuing quest for sustainable development already expressed by the *Millennium Development Goals (MDGs)* for the period 2005 to 2015. The seventeen SGDs cover a wide range of aspects of the global society and our interaction with the Earth system (Fig. 11). For each SDG, there are a number of associated Targets, which def ne the milestones to be reach by a certain time (see Fig. 12 for the example of SDG 6: Clean Water and Sanitation).

Being able to measure progress towards the targets associated with the SDGs requires metrics def ned by a set of indicators. Developing indicators that provide useful quantitative metrics is a long process

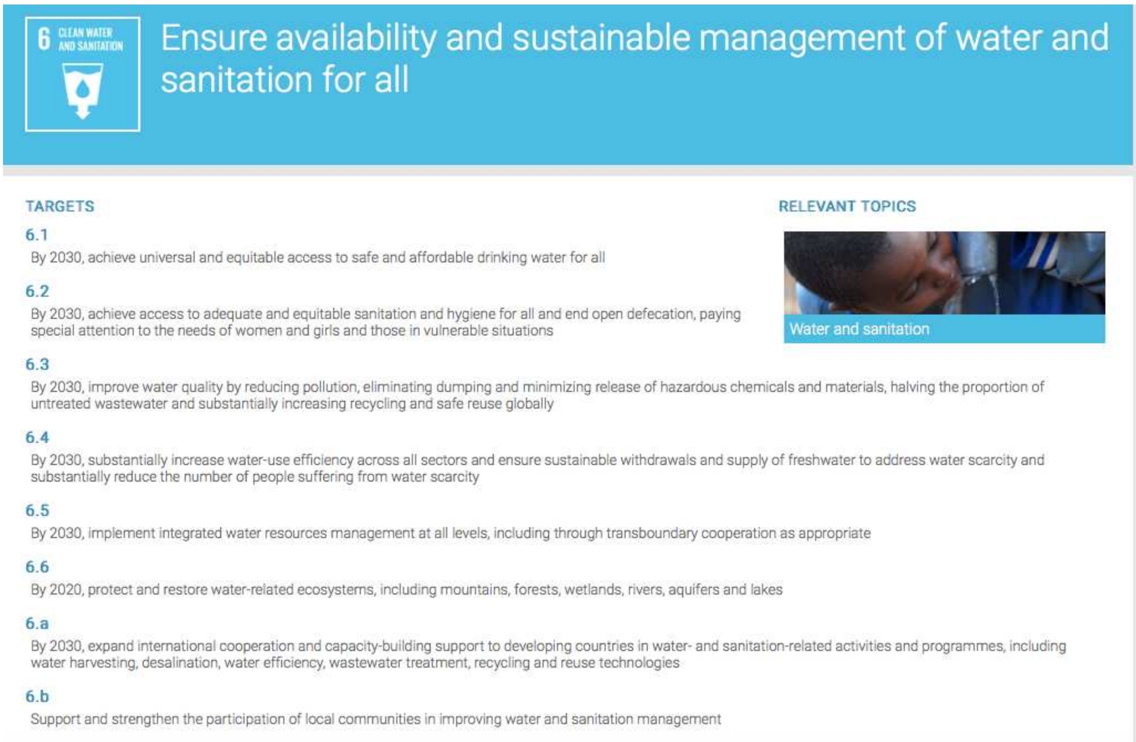


Figure 12. Targets associated with SDG 6.
From https://sustainabledevelopment.un.org/sdg6. Many of the targets associated with the SDGs have environmental aspects integrated and the corresponding indicators require EOs for quantification.

involving the scientif c community (Fig. 13). The proposed sustainable development indicators are discussed, for example, in Leadership Council of the Sustainable Development Solutions Network (2014). Rules for embedding environmental aspects into the SDGs and the metrics are discussed by Alcamo et al. (2013).

The most recent state is that the global indicator framework, to be developed by the Inter Agency and Expert Group on SDG Indicators, will be agreed by the UN Statistical Commission by March 2016 and adopted thereafter by the Economic and Social Council and the General Assembly, in line with existing mandates. This framework will be simple yet robust, address all SDGs and targets including for means of implementation, and preserve the political balance, integration and ambition contained therein (see http://unstats.un.org/sdgs/iaeg-sdgs/). The indicators are grouped into gray and green indicators. In a report to the UN Statistical Commission, the most up-to-date list of indicators prepared by the Inter-Agency and Expert Group on Sustainable Development Goal Indicators is communicated (Inter-Agency and Expert Group on Sustainable Development Goal Indicators, 2015).

Reaching from the SDGs indicators to the EVs required to quantify these indicators is a process that needs to be informed by the scientif c community. Based on the ministerial guidance provided at the 2014 summit, the GEOSS Knowledge base will be a place to have the deliberations required to link the SDGs Indicators to *Essential SDG Variabless (ESDGVs).*

Importantly, while most of the SDGs integrate environmental aspects, the indicators listed in citeIAEG2015 are predominately socio-economic in nature. It will be of value to link targets to additional relevant environmental indicators and corresponding EVs.

Figure 13. Indicators for SDG 6.
From https://sustainabledevelopment.un.org/topics/indicators.

Table 2. Societal Goals and Associated Targets, Indicators, and EVs.

Area	Goal(s)	Target(s)	Indicator(s)	EVs
Global Change	Comprehensive Archive of global change	Comprehensive Monitoring	Global Change indicators	EGCVs
Global Boundaries of SOSH	Staying within the SOSH	Reducing excess of boundaries	Global Boundary Indicators	EGBVs
Sustainable Development	Safeguarding the ELSS	Maintaining healthy subsystems of the ELSS, e.g., ocean, ecosystems	ELSS Health Indicators	EHPVs
Sustainable Development	SDGs	SDG Targets	SDG Indicators	ESDGVs

4.6 Overview of Societal Goal Sets

The societal goal sets discussed in the previous sections are summarized in Table 2. It is obvious that there will be considerable overlap between the EVs for each of these four goal sets. Therefore, an integrated set of EVs well linked to societal benef ts could provide valuable guidance for the prioritizing of EO investments.

All the EV sets discussed in the different GEO SBAs and other observing system communities are expert-based (see Deliverable D2-2 for a review). The ones resulting from the goal and target sets considered in the previous sections are goal-based. While expert-based EVs are generally domain or subject specif c, goal-based EVs will vary from goal set to goal set and also depend on the associated targets and the indicators def ned to monitor these targets. While expert-based EVs ref ect the observational needs and capabilities in a given domain in order to improve understanding, monitoring and predictive capabilities, the goal-based EVs are essential for monitoring progress towards societally agreed targets.

For the expert-based EVs, a goal is to integrate all domain-specif c EV sets into a general set of EVs to support prioritization. Similarly, if different goal sets are use to identify corresponding sets of EVs, it is

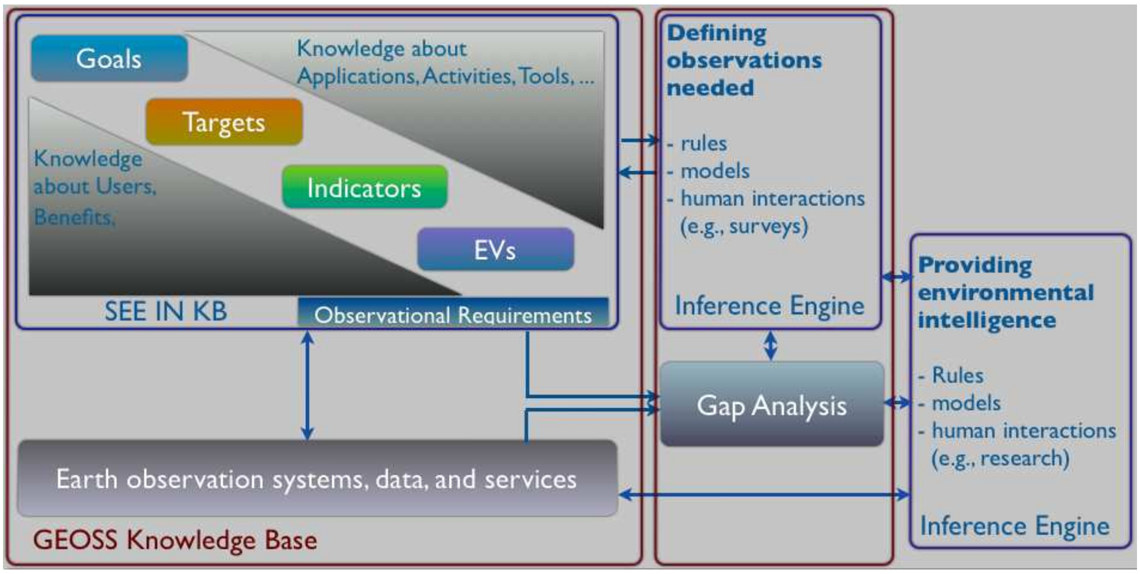


Figure 14. The GEOSS Knowledge Base.

desirable to aggregate these EVs into a general goal-based EV set supporting prioritization.

For expert-based EVs, the processes that leads to the acceptance in a community of the EVs is in general a consensus-building deliberation in the community. For goal-based EVs, the consensus-building societal processes focuses initially on the goals and targets as well as the indicators, with the latter requiring considerable input from the scientific community. The step from indicators to the corresponding variables that are essential for quantifying the indicators is a more scientific process, which can be described in blue prints. It is the goal to make these blue prints available as part of the GEOSS Knowledge Base.

5 The GEOSS Knowledge Base

5.1 Structural Model

In this section, we introduce key features of the GEOSS Knowledge Base that are of direct relevance to the ConnectinGEO Methodology for linking societal goals to EVs. A core element of the GEOSS Knowledge Base is the chain that connects societal goals via targets and indicators with EVs that was discussed in Section 3.2 (see Fig. 6). As discussed previously, the functions of the GEOSS Knowledge Base include the identification and documentation of societal knowledge needs and the resulting observational requirements, the support of user access to existing observations and services meeting knowledge needs, and a gap analysis (Fig. 14).

At its core, the GEOSS Knowledge Base consists of a repository that implements the generic knowledge base in form of a unstructured object data base combined with an inference engine to define observations needs for identified goals and knowledge requirements. This part is what is called the SEE-IN Knowledge Base.

The SEE-IN Knowledge Base is linked to an interface with a collaborative environment that allows deliberations about, and a "social" consensus on, the objects in the SEE-IN Knowledge Base and the rules in the inference engine. This interface is denoted as a VST.

Around this core, the GEOSS Knowledge Base will include a repository with information about existing EOs and services. Here EOs are defined as all observations of the Earth system independent of how these observations are obtained or which part of the Earth system they characterize. A second inference engine will contain the rules for gap analysis and prioritization. The details of this part will be described in a separate document (D6_2 of ConnectinGEO).

5.2 The SEE-IN Knowledge Base

The SEE-IN repository is being filled with a number of different objects, including but not limited to

- Observation requirements;
- User types;
- Applications;
- Essential variables;
- Indicators and indexes;
- Targets;
- Goals;
- Scientific challenges;
- “What if ...” scenarios.

To capture interconnectivity between these objects, the concept of links between objects is used to represent chains of objects. This provides the basic model for the repository.

The data model of the SEE-IN Knowledge Base (see next section) is based on the URR and captures all elements represented in the URR. The main relations in the URR initially included User Types, Applications, and observational Requirements (Fig. 15). Based on user requests, four need were added for Capacity Building, Technology, Infrastructure, and Research. Pairs of entries in any of these relations can be linked through a Link relation, and this allows capturing interconnectivity along value chains from EOs down to the final end users. Information on societal benefits is captured in the Link entries. The contents of the URR allows for the analysis of networks (Fig. 16) and prioritization of observational requirements based on the number of links to applications and user types (Plag et al., 2012b).

5.3 Data Model of the SEE-IN Knowledge Base

There are three main schemes in the SEE-IN Knowledge Base: (1) a user and societal benefits-based description of the world (Fig. 17); (2) an analysis part that links observations to science challenges or agreed-upon societal goals (Fig. 18); and a blue-print schemes that allows to generate elements in the above two schemes base on a set of rules (Fig. 19). The first scheme is closely aligned to the approach of the URR and represents more the expert-based approach to linking EOs and societal benefits. The second scheme is more aligned to the ConnectinGEO methodology of an goal-based approach. The third scheme can be applied to linking indicators to EVs.

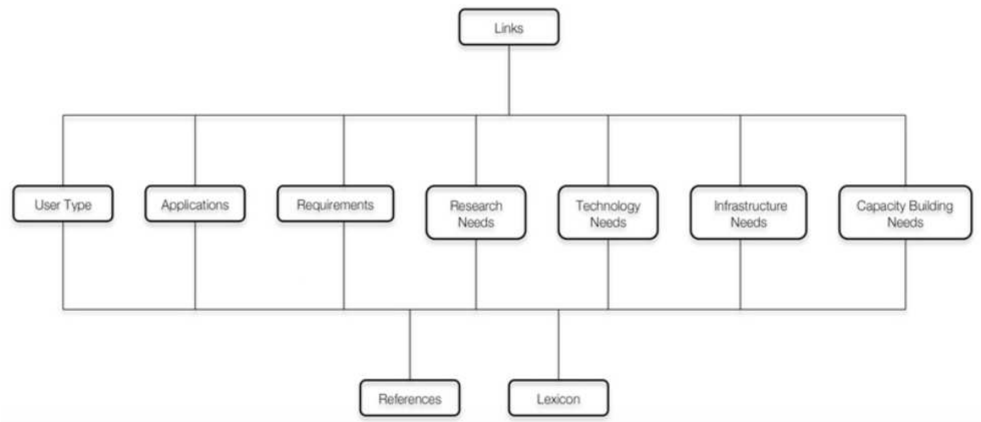


Figure 15. Data Model of the GEOSS User Requirements Registry.
Pairs of entries in any of the seven core relations of the URR shown in the middle row can be linked through entries in the Links relation to capture connectivity along chains from EOs to end users or in networks connecting entries in these seven relations. Ontologies and controlled vocabularies are contained in the Lexion, and references to relevant documents are in References.

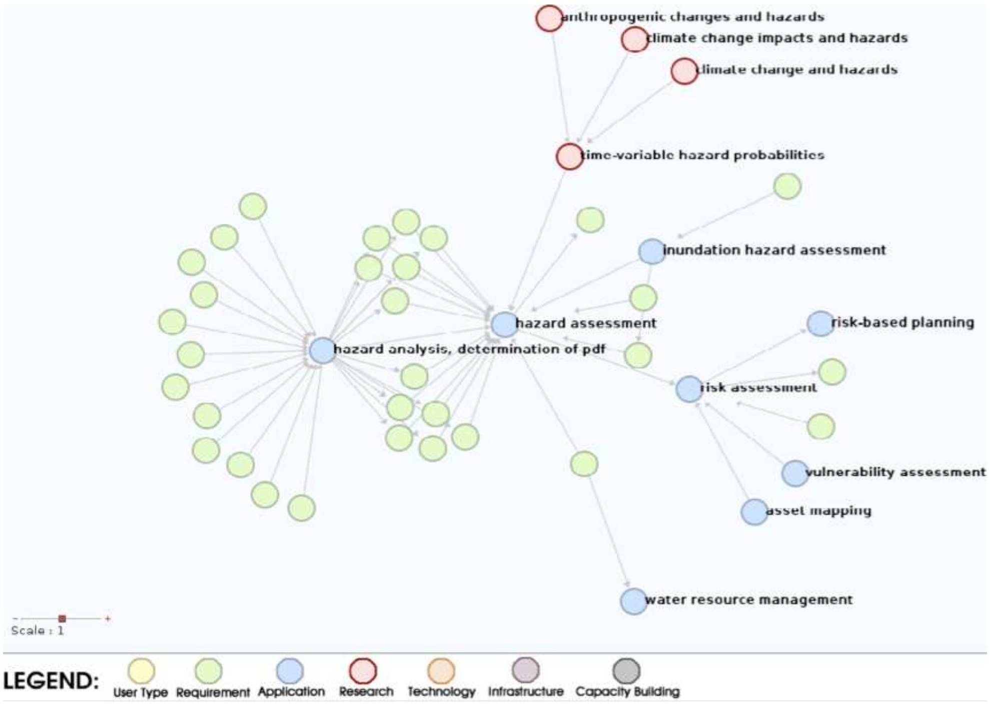


Figure 16. Network Character of Information Stored in the URR.
The information stored in the URR allows the construction of networks of elements to show connectivity and to assess the societal benefits of different elements along the value chain from EOs to end users.

The f rst scheme (Fig. 17) is centered around societal benef ts that are specif ed by users. The GEO ***SBAs!****s* ***(SBAs!****s)* are linked to multiple societal benef ts. The societal benef ts in general contribute to the "wisdom" category expressed in societal goals.

In general, societal benef ts are realized through applications that make use of observational data. Re-

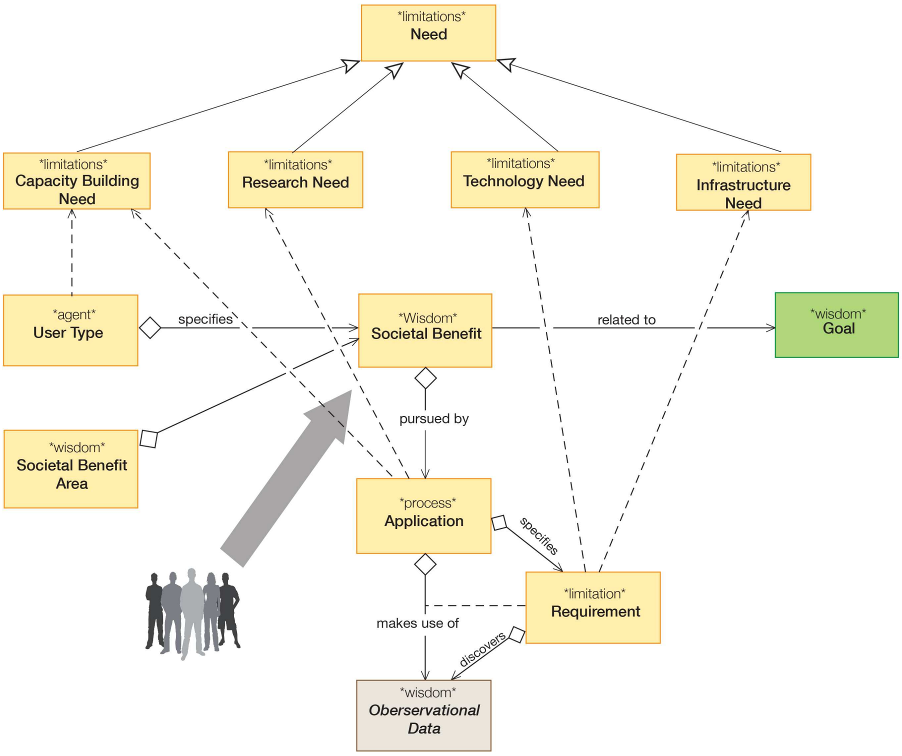


Figure 17. Societal Benef ts and EOs.

quirements specify the data and data products needed by applications, and theses requirements can be used both to discover the data needed as well as to identify gaps resulting from missing data.

There are several needs that express current limitations to realize the societal benef ts. The benef ts themselves may depend on research needs to better understand the conditions of the benef ts. User types may also identify capacity building needs in order to utilize EOs and applications to realize the benef ts and/or to better understand the benef ts. Utilizing the applications to a full extent may depend on capacity building as well as research. Meeting certain requirements may be limited by a lack of suff cient observational or processing infrastructure, and observing specif c variables may be limited by a lack of technology.

The second scheme (Fig.18) takes a starting point in goals and targets that are in the “wisdom” category and resulting from societal consensus-building deliberations. The indicators corresponding to the targets are in the “knowledge” category and provide the means to monitor and manage progress to the targets. Several indicators can be combined to create complex indexes. The integration of all indicators and indexes discussed in Section 4 would lead to a global Sustainability Index.

Indicators make use of EVs required for their quantif cation. The quantif cation of indicators uses an algorithm, a so-called “blue print,” and this blue print can also be used to identify the EVs.

Data for the EVs are generated by observations, and the link between observational data and the EVs in general involves another algorithm. The resulting specif c information on the EVs is of value by itself.

To assess planned action, “What if” questions can be posed to understand the impact on EVs and indicators. Again, this requires an algorithm in form of a blue print. The “What if” questions are in the “wisdom” category, and in general, a consensus-focused deliberation is required to decide which “What if” to ask.

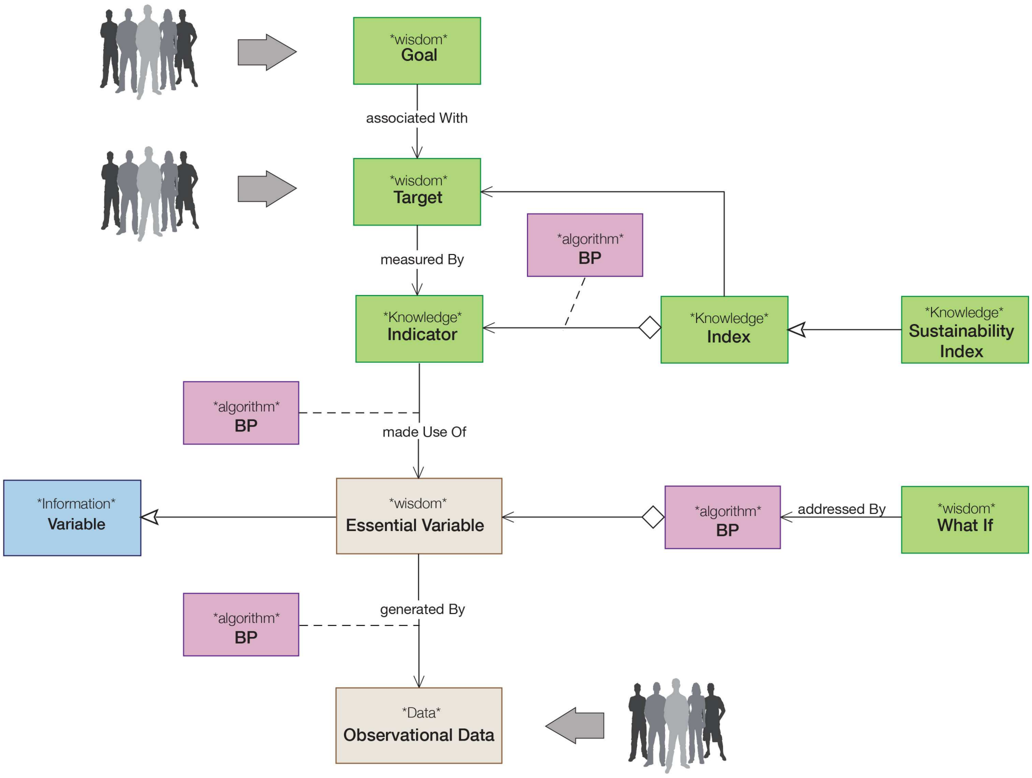


Figure 18. Analysis of Societal Challenges.

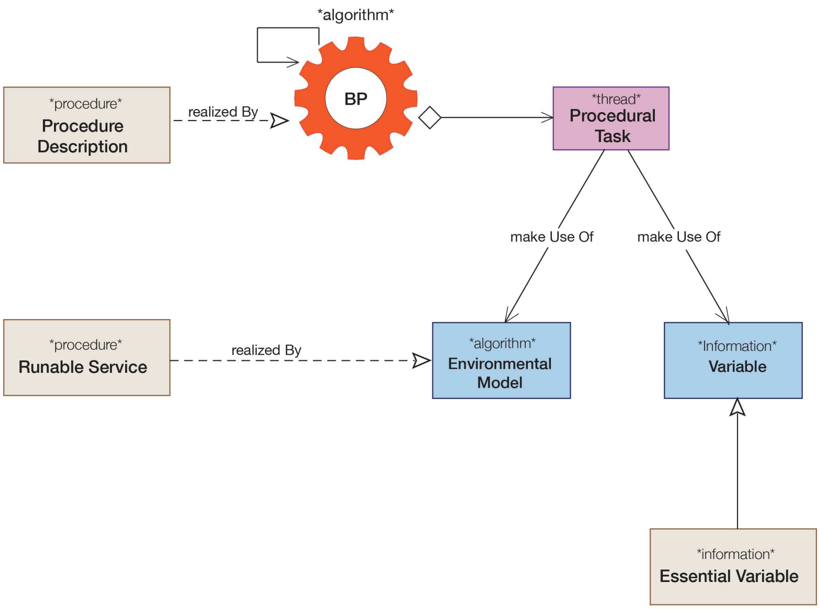


Figure 19. Blue Print Scheme.

The third scheme (Fig. 19) provides more details on the blue prints used to generate different elements in the previous two schemes. A procedure description is used to def ne the algorithm denoted as the "business process," which is connected to one or more procedural tasks. These tasks make use of environmental or socio-economic models and information on EVs. The runnable service is realized through the models.

6 Conclusions

The ConnectinGEO Methodology for an goal-based approach to the identification of EVs is complimentary to the expert-based approach that is widely used in scientific and other communities engaged in Earth observations. The starting point are agreed-upon societal goals that can be associated with specific targets to be achieved in a given time interval. Progress is measured based on metrics provided by indicators. The ConnectinGEO Methodology adds to this process the steps that leads from the indicators to the EVs required to quantify the indicators in such a way that they provide a report card for the monitoring of progress.

There are a number of different societal goal sets that could benefit from the availability of EOs of the relevant EVs. Although we have reviewed several examples, there are many more that could be introduced. For example, in the frame of risk reduction and governance, societal discussions are focusing on societal goals that would significantly benefit from EOs of relevant EVs.

In order to prioritize investments in EOs, it would be helpful to make an explicit choice of which societal goals have highest priority in GEO's effort to meet their observational and information needs. This choice could be based on an assessment not of the goals themselves but rather the impact EOs and information on EVs could have for reaching the targets.

The GEOSS Knowledge Base could play a central role for this assessment. It will be important to develop the Knowledge Base such that it can capture the full complexity of goals, targets and indicators and connect them to EVs and EOs. This will require to implement the Knowledge Base as an open environment that can be further developed in a collaborative effort and to build strong crowd-sourcing tools into it.

PART 2:

WORKSHOP REPORT: *NAVIGATING SUSTAINABILITY ON A CHANGING PLANET*

Edited by Hans-Peter Plag

1 Goals and Objectives of the Workshop

Informing Sustainability: 2015 is a year of important decisions preparing humanity's Road to Dignity. Our leaders need comprehensive information about the state and trends of the planet, including our global society, to make progress on this road to sustainability and dignity. The workshop linked societal goals to essential variables needed to measure progress towards these goals and discuss research innovations in support of sustainable development.

Our planet is rapidly changing and moving out of the Holocene. Navigating and managing the changes and maintaining a sustainable development is complex. We need to have goals and targets related to sustainable development, understand the limits of what is a safe and sustainable development, know the ongoing changes, and have foresight about the impact of our actions on the planet. The workshop brought together the science that links our goals with the "navigation tools," that is, the indicators of change, and the Earth observations required to quantify these indicators.

A main outcome of the United Nations Conference on Sustainable Development (Rio+20), held in June 2012 in Rio de Janeiro, was the agreement by Member States to initiate a process to develop a set of "Sustainable Development Goals" (SDGs). Motivated by the partial success during the decade from 2005 to 2015 of achieving the "Millennium Development Goals" (MDGs), the SGDs would serve as the driver for progress towards the decade from 2015 to 2025. Since RIO+20, a number of groups have been active in developing the set of goals, with the Open Working Group on Sustainable Development (OWG) being central in the process. In July 2014, the OWG published its proposal for the SGDs (see the Outcome Documents of the 13th Session of the OWG), and in December 2014, the Secretary General added a synthesis report detailing The Road to Dignity. Both, for MDGs and SDGs, metrics that can measure progress towards the goals are important. The OWG has identified a set of indicators for the

SDGs, which aim for consistency with the indicators used for the MDGs. These indicators are currently refned by technical teams. Many of these indicators are environment-related and require comprehensive Earth observations for a reliable quantifcation.

The concept of a safe operating space for humanity (SOSH) is central to sustainability. The global boundaries of the SOSH are partly known quantitatively, and partly blurred, with potential thresholds still unknown. A better quantifcation of the boundaries and a monitoring of the state of the planet with respect to these boundaries depends on comprehensive Earth observations.

Major scientifc organizations have identifed grand research challenges that need to be addressed in order to provide the knowledge needed to make progress towards global sustainability. The required research also depends on a comprehensive and accessible Earth observation database. Research innovations are needed at many scales to address the grand challenges and to make progress towards the societal goals.

The Group on Earth Observations (GEO) is implemented the Global Earth Observation System of Systems (GEOSS) with the goal to improve access to, and the use of, Earth observations for a broad range of stakeholders. The 10 Year Implementation Plan for GEOSS endorsed by a Ministerial Summit in 2005 states "GEOSS was 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." The Ministerial Summit on Earth Observation held in January 2014 in Geneva (see meeting documents) underlined the importance of the SGDs and of GEO focusing the development of GEOSS on the information needs that arise from humanity's quest for the SGDs.

The Implementation Plan Working Group (IPWG) initiated during the Ministerial Summit in 2014 with the mandate to draft the next 10 Year Implementation Plan for GEOSS provided in March 2015 a frst report summarizing the frst "refective phase" of the IPWG and laying out the scheme for the further development of GEOSS. At the XI GEO Plenary, the IPWG provided a draft Strategic Plan. The workshop built on these reports and discussed the science and metric needed to achieve the goals indicated in these report.

With this in mind, the 3rd GSTS Workshop focused on the knowledge needs of the global and national decision makers to enable progress towards global sustainability on a changing planet. The workshop used the priorities of the discussion on the SGDs, the preliminary indicators, the grand challenges identifed by ICSU and the Belmont Forum, and the global boundaries of the SOSH as a starting point in the discussion of the science of sustainability indicators with the goal to make progress towards a comprehensive sustainability metrics. The workshop addressed to what extent the current and planned Earth observation systems would allow a quantifcation of the indicators comprising this metrics.

Outcomes of the workshop include recommendations for the future focus of GEO and GEOSS on grand challenges and the societal goals addressing these challenges. It is recommended that GEO is opening to a broader community including the private sector and that GEOSS utilizes new observation types. It was emphasized that there is a need to evolve both GEO and GEOSS with the changing view on what is needed and a changing technological environment.

Scientists and researchers engaged in environmental research supporting the previous MDGs and the current SDGs and addressing the grand challenges are key stakeholders of GEOSS. Aligning the governing strategy for the implementation of GEOSS to the needs of these stakeholders should have a high priority for GEO. The workshop reviewed the support of GEOSS for research on global sustainability and provided guidance on how to improve this support.

2 Summary of Workshop Findings

3 Conclusions and Recommendations

The 3nd and 4th GEOSS Science and Technology Stakeholder Workshops held in Norfolk, VA, USA on March 23-26, 2015 reviewed two key aspects of the future development of GEOSS, that is, the alignment of the efforts to the grant challenges associated with humanity's quest for a sustainable development on a changing planet and the opportunities arising from new concepts and for future earth observation and information systems serving the needs of growing user communities.

The workshops were organized by the GSTSN together with a total of 20 international research organizations, United Nations agencies, funding agencies, and research projects funded by the European Commission.

The workshop participants noted the many efforts made by the international community to make progress towards a more sustainable world, identif ed "big issues" that need to be addressed in this quest, emphasized the need for a focused research effort to support decision makers, policy makers and the public in making progress towards increased sustainability and resilience, elaborated on the many opportunities arising from new technologies and new concepts for data collection, information and knowledge creation and dissemination, introduced new user groups for earth observations and GEOSS, and urged the Member Countries and Participating Organizations of GEO to make an effort to utilize these opportunities to provide the data and infrastructure needed to create and access information and knowledge derived from Earth observations.

Addressing the global challenges, the Workshop participants emphasized that

- Climate change and the grossing of global boundaries of the safe operating space for humanity poses threat to sustainable development;
- Adaptation to the changes in the polar regions is challenging security;
- Food and water security are at risk due to increasing droughts, f oods, and heat waves at the same time as demand for food is growing;
- Population growth and escalating migration are an increasing threat to international stability and a challenge for both the developing and developed world;
- Disaster risk management and developing resilient communities is an urgent matter considering that growing populations are exposed to hazards and mega cities are sprawling into hazardous areas;
- Tipping points in the coupled socio-economic and environmental system may be crossed due to global and climate change and social and economic development;

With respect to the international activities, it was underlined that

- The international community has made progress towards new frameworks for sustainable development, disaster risk management, climate change mitigation and adaptation, and a global f nancial system aligned to the needs of sustainable development;

- All these efforts require indicators that provide the metrics to measure progress towards the articulated goals and targets and support the planning of actions and development of policies in support of implementation;
- Most of the indicators considered require significant Earth observations integrated with socio-economic data;
- There is a high economic costs associated with the uncertainties resulting from insufficient or incomplete observing systems;
- There is a need to have a planetary dashboard providing timely warnings in cases where tipping points might be crossed;

The workshop deliberation acknowledged the efforts made by GEO to

- Stimulate global and regional initiatives for the coordination of Earth observation networks and the development of existing and new observing systems;
- Identify the essential variables in each of the Societal Benefit Areas with particular focus on those required to quantify the indicators and to improve predictive capabilities;

Based on these considerations, the participants identified the needs that the Strategic Plan of GEO:

- Defines GEOSS as a knowledge hub that directly serves countries and international efforts at the highest political level to enhance policy formulation and impact of policy implementation to achieve tangible benefits of societal development;
- Addresses the information needs of decision and policy makers at international and national levels;
- Emphasizes the mandate of GEOSS and its global role to provide the science and observation base for making development policies and decision-making relevant at the level of the commonwealth of nations worldwide including high-level capacity building;
- Underlines the need for co-design of the GEO agenda and co-creation of knowledge and anticipates the incorporation of decision and policy makers from beginning of GEO activities to the tailored delivery of the results;
- Outlines a governance structure that provides structure and processes bringing together the different implementation elements into a coherent effort where the whole is significant larger than the sum of the individual efforts;
- Clarifies the role of, and requirements for the composition of, GEO Initiatives and Flagships;
- Acknowledges the importance of the development of a GEO Knowledge Base which documents the societal information needs linked to observational requirements and includes best practices and compelling examples that showcase how data, technology and communities move from basic to applied research and support for policy and decision-making;
- Elaborates on the need for a gap analysis across all societal issues based on a fully populated GEO Knowledge Base with the goal to inform prioritization of efforts in Earth observations;

Concerning the future community coordinating GEOSS implementation, they recommended to make provisions for the future GEOSS to

- Facilitate new data and big data integration and to address relevant policies and issues, including privacy, anonymization, processes to control use, legal interoperability, and quality labeling and trust processes.;
- Increase accountability, traceability, and attributability through data citation and a consistent digital object identification system;
- Develop an e-infrastructure that supports open access, legal interoperability, education, and changing data culture;
- Strengthen cooperation through and open source environment that supports coordination, sharing of infrastructure and data, and allows for extensive community contributions;
- Serve as a forum for airing issues and problems that is complementary to other efforts;

With respect to the opening of GEO for the private sector, the participants asked the GEO community to work with the private sector to

- Shape GEO to involve a bigger constituency;
- Open GEO for Participating Organization originating in the private sector.

4 Additional Material

4.1 Workshop Organizers

Program Committee

- GEOSS Science and Technology Stakeholder Network: *Hans-Peter Plag, Stefano Nativi*
- Group on Earth Observations: *Douglas Cripe*
- GEO Institutional Development Implementation Board *Stuart Marsh*
- GEO Societal Benefits Implementation Board: *Rick Lawford/Khondar Rifat Hossain*
- GEO Water Cycle Community of Practice: *Rick Lawford*
- World Health Organization: *Khondkar Rifat Hossain*
- Belmont Forum: *Maria Uhle*
- European Science Foundation: *Paola Campus*
- Earth Science Information Partnership: *Erin Robinson*
- European Commission: *Michel Schouppe*
- ConnectinGEO: *Joan Maso*

- World Data System: *Mustapha Mokrane*
- CODATA: *Alex Sherbenin/Bob Chen*
- IEEE/OES: *Hans-Peter Plag, Jay Pearlman*
- IGBP: *James Syvitski*
- ISSC: *Heide Hackmann/Sarah Moore*
- IUGG: *Peter Fox*
- START: *Hassan Virji, Senay Habtezion*
- UNU-EHS: *Jörg Szarzynski*

Local Organizing Committee (hosted by Old Dominion University, Norfolk, VA, USA):

- Hans-Peter Plag
- Chris Campbell
- Yongcun Cheng
- Judy Hinch
- Shelley Jules-Plag
- Elizabeth Smith

4.2 Workshop Participants

The Workshop was open to all GEOSS Science and Technology Stakeholders. Participants represented science communities engaged in research related to sustainability indicators, SDGs, global boundaries, and/or Future-Earth topics, United Nations' agencies involved in SGDs related processes; or communities involved in the provision of Earth observations and the implementation of GEOSS.

4.2.1 Statistics

The geographical distribution of the participants is shown in Fig. 1. The participants were more or less equally distributed in North America and Europe, with very little participation from outside these regions. Most participants participated in both workshops (Fig. 2).

Figure 1. Geographical Distribution of the Participants.

Figure 2. Geographical Distribution of the Participants.

4.2.2 List of Participants

R: Remote participation; WS3: 3rd Workshop; WS4: 4th Workshop.

Last Name	First Name	Affiliation	Country	R	WS3	WS4
Arctur	David	University of Texas	US		x	x
Azzolini	Roberto	CNR	Italy		x	
Bigagli	Lorenzo	Consiglio Nazionale delle Ricerche	Italy			x
Blonda	Palma Nicoletta	CNR-ISSIA	Italy		x	x
Bohn	Robert	NIST	US			x
Bombelli	Antonio	CMCC-Euro-Mediterranean	Italy		x	
Bourassa	Mark	Florida State University	US		x	
Browdy	Steven	OMS Tech	US		x	x
Budai	Jeffery	National Centers for Environmental Information	US		x	x
Bye	Bente Lilja	BLB	Norway			x
Callihan	Heather	ESRI	US			x
Campus	Paolo	European Science Foundation	France		x	
Chen	Robert	Columbia University	US			x
Cripe	Douglas	GEO Secretariat	Switzerland		x	x
De Lathouwer	Bart	Open Geospatial Consortium				x
Dettmann	Carsten	Ministry of Transport and Digital Infrastructure	Germany		x	x
Druckenmiller	Matthew	US Agency for International Development	US		x	
Eberle	Jonas	University of Jena, Germany	Germany		x	x
Favors	Jamie	NASA DEVELOP National Programs	US			x
Fontaine	Kathleen	RPI	US		x	x
Grabs	Wolfgang	BFG	Germany			x
Habtezion	Senay	START - global Change SysTem for Analysis, Research and Training	US		x	x
Haklay	Muki	University College London	US	X		x
Hamlington	Ben	Old Dominion University	US		x	
Johnson	Shawana	Global Marketing Insights, Inc.	US		x	x
Jones	Dave	Stormcenter	US			x
Jules-Plag	Shelley	ODU	US		x	
Katz	Daniel S.	University of Chicago	US			x
Kerr	Thomas	Global Marketing Insights, Inc.	US		x	x

Last Name	First Name	Aff liation	Country	R	WS3	WS4
Lee	Hyunrok	APEC Climate Center	Korea		x	x
Lee	Craig	The Aerospace Corporation	US			x
Lenton	Tim	University of Exeter	U.K.	X	x	
Lovison-Golob	Lucia	Afriterra Foundation	USA			x
Maso	Joan	Universitat Autonoma de Barcelona	Spain		x	
Mazzetti	Paolo	Consiglio Nazionale delle Ricerche	Italy		x	x
Mlisa	Andiswa	GEO	Switzerland		x	x
Nativi	Stefano	Consiglio Nazionale delle Ricerche	Italy		x	x
Nesje	Oystein	Climate and Environment, Norway	Norway		x	x
Ochiai	Osamu	Group on Earth Observations	Switzerland		x	
Ojima	Dennis	CNU/Future Earth	US			x
Pearlman	Francoise	IEEE Committee on Earth Observations	US		x	x
Pearlman	Jay	IEEE Committee on Earth Observations	US		x	x
Plag	Bombeli	Old Dominion University	US		x	x
Remetey	Gabor	Hungarian Association for Geo-Information	Hungary			x
Saad	Merna	NASA DEVELOP Program	US		x	
Sahagian	Dork	Leghig University	US		x	
Schouppe	Michel	European Commission - DG RTD	Belgium			x
Shanley	Lea	NASA Headquarters	US	X		x
Shrestha	Ranjay	Center for Spatial Information Science and Systems	US		x	x
Syvitski	James	University of Colorado	US		x	x
Tanhua	Toste	GEOMAR	US	X	x	
Turner	Andrew	Esri	US			x
Wee	Brian	NEON, Inc.	US			x
Wielicki	Bruce	NASA Langley Research Center	US		x	
Yetman	Greg	Columbia University	US			x
Yu	Eugene	George Mason University	US			x

4.3 Session Overview

The program included plenary session that featured invited high-level presentations to introduce core themes. Subsequent breakout sessions focused on sub-themes and consisted of short presentations, panels, and discussions. After each breakout sessions, a plenary session summarized the outcomes of the breakout sessions and provide input for subsequent sessions.

The following sessions were conducted (text is pre-workshop version):

Plenary Session 1: Assessing and Managing the Changes: The Metrics

This session will summarize the knowledge about indicators for the state and trends in the Earth system, including the social component of this system. Particular focus will be on indicators related to the SDGs, the SOSH, and sustainable development in general. The science behind the indicators will be the starting point for presentations.

Breakout Sessions Block 1: Designing the Metrics

In the first block of breakout sessions, the focus will be on specific sets of indicators and the extent to which the indicators are linked to essential variables of the earth system.

Plenary Session 2: Assessment of the Metrics

Based on the previous plenary and breakout sessions, an assessment of the available metrics in terms of completeness, applicability, and decision support will be considered.

Breakout Sessions Block 2: Quantifying the Metrics

Based on the outcome of the previous breakout sessions, the sessions will consider the sets of essential variables for several goal sets (SDGs, SBAs, SOSH) and discuss availability and applicability of data for these essential variables that would allow quantification of these goal-related indicators.

Plenary Session 3: Monitoring and Foreseeing the Changes

The Role of Earth Observations Quantification of the indicators — the metrics — requires observations of the essential variables used to generate the indicators. This session will compare the available and anticipated observations of essential variables to the needs arising from the task, which is navigating sustainable development on a rapidly changing, dynamic planet.

Plenary Session 4: Setting Priorities

Based on the previous sessions, priorities for Earth observations will be discussed and translated into recommendations.

Joint Plenary Session A (Jointly organized with Workshop 4): Changing Science for a Changing Planet

The rapid changes in key variables of the planet (for example, biodiversity, atmospheric chemistry, ocean heat content, water cycle and sediment transport, ocean acidity, land cover, ice sheets, sea level) that are already taking place and expected to increase can lead to major challenges for humanity. We need to ask whether the current approach to science will be able to identify these challenges in a timely manner and provide the practice-relevant knowledge needed to address them, or whether a new approach to rapid knowledge creation is needed.

Joint Breakout Sessions Block (Jointly organized with Workshop 4): Creating the practice-relevant knowledge to cope with global change

The breakout sessions will review methods for knowledge creation related to key areas of global change while considering the potential for rapid changes that might challenge the traditional scientific approach.

Joint Plenary Session B (Jointly organized with Workshop 4): Linking Science, Metrics, and Observation Systems

In this session, we will aim to bring together science and goal-based metrics in order to better understand the requirements of future observing systems which will provide the data required to quantify the metrics and enable applications for societal benefits.

4.4 Workshop Minutes

Plenary Session 1: Assessing and Managing the Changes: The Metrics

Co-Chairs: Hans-Peter Plag, Stefano Nativi

This session set the stage for the workshop by summarized the knowledge about indicators for the state and trends in the Earth system, including the social component of this system and by introducing recent developments in GEO. The Workshop was opened by a welcoming note delivered by Douglas Cripe, GEO Secretariat and Hans-Peter Plag linking the present workshop to the previous two workshops. Douglas Cripe introduced the participants to the strategic work in GEO in preparation of the post-2015 period. Tim Lenton emphasized the need to anticipate tipping points that could hamper sustainable development.

Breakout Sessions Block 1: Designing the Metrics

In the first block of breakout sessions, themes focused on specific goal sets and the indicators used in relation to these goals. The sessions reviewed to what extent the indicators are linked to essential variables of the Earth system. The objective was to discuss and draft sets of essential variables for each of the goal sets.

Breakout Session 1.1: Sustainable Development Goals, Global Boundaries, and Safe Operating Space for Humanity

Chairs: Hans-Peter Plag; Rapporteur: Senay Habtezion

Hans-Peter Plag introduced the topic and referred to the GEO Ministerial summit on EOs (Jan 2014), which emphasized the importance of SDGs and asked GEO to focus in the development of GEOSS on the information and knowledge needs for SDGs. There is a need for a framework for defining and documenting observations and comprehensive sustainability metrics. EOs play a key role in this, but they need to be combined with socio-economic data and merged with data.

In the discussion, the question of how can we measure progress towards achievement of the SDGs was raised. It was clarified that the indicators are a management tool and a report card for progress toward the SDG targets. Another question raised was whether GEO could contribute to a refinement of the indicators or just focus on the EVs for the pre-defined indicators. A role for GEOSS could be to develop a sustainability information framework allowing pulling out relevant information from GEOSS. A role for GEO could be to serve as a forum to others not necessarily represented within the UN process, for example, businesses.

It was recommended that the declaration for the upcoming Ministerial Summit in 2015 would include a commitment of the GEO Member Countries to use GEOSS.

Concerning the SDGs that were proposed, it was commented that in light of broad nature of the proposed goals and targets, GEO may need to prioritize and focus on key SDG targets that contribute most to sustainability.

Breakout Session 1.2: GEO Societal Benefit Areas

Chairs: Antonio Bombelli; Rapporteur: Mark Bourassa

Antonio Bombelli introduced the questions to be addressed, i.e., (1) What process and criteria could be used to develop indicators that can serve as a management tool to support planning and a report tool to support assessments of progress? and (2) How developed are indicators in a given area of societal goals? He used the example of CO_2 to illustrate the importance of understanding the information needs associated with a given variable.

The discussion around the questions resulted in a number of comments. Deciding on which societal goals to focus is a difficult task because the scope is large. The process of looking at the possible goals was like pealing an onion – always more layers. The GEO SBAs, impacts, science issues and variables are separate issues but related and it is difficult to determine where to start. There needs to be a strategy to engage stakeholders and other groups already invest in these topics. Different indicators are needed for political applications than those used in scientific applications, and the understanding of requirements for different applications needs to be improved. Indicators of warnings (i.e., increased risk) could come from production, logistics, population dynamics as well as environmental variables.

It was emphasized that models are needed for forecasts, and data are needed as input for these models and for model development. Developing predictive capabilities and understanding the processes requires observations with much better temporal and spatial resolution than those needed to identify changes in the climate system. For the latter, knowing the short-term fluctuations and extremes is important. The science metrics (quantitative) must be linked to risk and the GEO SBAs. An indicator example considered was the ratio of magnitude of earthquakes to loss of lives (risk) modulated by local preparations. The quantitative indicators should be linked to risk. Disasters in one location are linked to changes in demand in other areas. There is a need to link the SBAs to scientific goals and these in turn to required observations.

The types of indicators discussed included:

- measurement of physical change;
- measurement of progress on science objectives;
- measurement of impact (use as well as real impact).

It was concluded that GEO should act as a forum to bring together groups with a vested interest in the topic. For communications purposes, the need for observations and modeling needs to be linked to the SBAs.

Plenary Session 2: Assessment of the Metrics

Chair: Jay Pearlman

The session was opened by Jay Pearlman introducing the rapporteurs of the previous breakout sessions and the two keynote speakers of the session. The breakout session reports (see above for details) were presented by Senay Habtezion and Mark Bourassa, respectively.

Ben Hamlington gave a summary of the knowledge about past and current sea level changes. He emphasized that sea level is an essential climate variable that provides important insight into the state of the climate. Changes in sea level reflect both thermal expansion from rising ocean temperatures as well as well as mass-change due to increased run-off from ice sheet and glacier melt. Changes in sea level also pose a direct and serious societal and economic risk. In the past two decades, satellite measurements have improved our understanding of sea level, and a number of studies on the driving processes have led to closure of the sea level budget. There is a need to continue the satellite-measured sea level record into the future. There are still many questions to be answered with regards to future sea level. There is a growing need to communicate uncertainties more clearly. He pointed out that there is a possibility that the “likely” range of future sea level rise is underestimating the full range.

Thorsten Tanhua reviewed the efforts in the ocean observing community to identify EOVs. He underlined that feasibility of observations has a high weight in defining the EVs and most of the efforts are focused on the upper right corner of the impact versus feasibility diagram, i.e. high feasibility and high impact. The connection to societal goals takes place after the EVs have been identified. The procedure is fully expert-based.

Based on the previous plenary and breakout sessions, an assessment of the available metrics in terms of completeness, applicability, and decision support was attempted. There was considerable discussion about the role of GEO in defining and quantifying metrics. There was a consensus that GEO had an important convening function and that the focus of GEO should be on providing the EVs for the quantification of indicators that compose the metrics.

Breakout Sessions Block 2: Quantifying the Metrics

Based on the outcome of the breakout session of the first day, the breakout sessions will consider the sets of essential variables for several goal sets (SDGs, SBAs, SOSH) and discuss availability and applicability of data for these essential variables that would allow quantification of these goal-related indicators.

Breakout Session 2.1: Essential Variables for Sustainable Development Goals, Global Boundaries and Safe Operating Space for Humanity

Chair: Hans-Peter Plag, Rapporteur: Senay Habtezion

The session addressed four key questions related to EVs:

- WHAT: Definition of EV
- WHY: Why should GEOs provide description of indicators?
- HOW: What process is desirable and feasible to provide description of Evs?

- WHO: Who would use a template for description of EVs (communities of practice)

Several of the proposed SDG indicators were used as examples to discuss the status to which EVs are identified for these indicators. Most of the discussion focused and a template for the description of an EV. It was agreed that for the goal-based approach, the template should include the following fields:

- Describe the societal goal(s) that have a linkage to the EV
- Describe the societal target(s) or equivalent entities that are linked to the indicators
- Describe the indicator(s) that depend on the EV
- Describe the system relevance of the EV, where system is the coupled human-natural system.
- Provide details on the system components for which the EV is essential
- Describe operational, forecasting, and discipline-specific relevance of the EV
- Describe the underlying data organization/management for the EV
- Describe the benefits of having the EV available

Concerning the definition of EVs, there was agreement that a process of how to identify an EV should be promoted. It was suggested that the use of models and empirical studies should be part of the process. Importantly, the expert-based approach starts a observational capabilities and progresses to societal benefits, while the goal- and target-based approach starts at the societal benefits and progressed to the EVs.

There was considerable discussion about the definition of EVs. The preliminary definition stated: "Variables that determine the system's state and developments, are crucial for predicting system developments, and allow us to define metrics that measure the trajectory of the system. Limited knowledge of essential variables implies limited predictive capabilities and limited means to measure where the system is heading."

It was pointed out that there may be a need to rephrase the suggested definition such that the there are two parts: one addressing the technical aspects of EV and the second dealing with Societal relevance.

In terms of societal relevance, it was pointed out that EVs should be crucial for the creation of practice-relevant knowledge. EVs are closer to knowledge than others.

There was consensus that EVs are domain specific. Different communities of practice have different approaches and are likely to characterize their variables their way. The role of GEO should be to recommend one or more processes for determining EVs but not to prescribe domain-specific variables. The question of how we can facilitate a coordinated deliberation of EVs in GEO was touched upon but remained open.

Breakout Session 2.2: Essential Variables for GEO Societal Benefit Areas

Chair: Antonio Bombelli, Rapporteur: Kathy Fontaine

Several of the GEO SBAs have started processes towards the identification of EVs. The breakout session will review the status of these initiatives and their approaches to linking these EVs to metrics. The goal is to give recommendations how a consistent process could be developed to be used in all SBA areas.

The session was opened by stating that tacking stock of the previous sessions the follow point should be addressed in the session:

- Analyze the sets of essential variables (EVs) identified for the different GEO SBA.
- Assess their completeness, applicability and usefulness in decision support.
- Address the issues that can limit their use: uncertainty, resolution, accuracy, cost-effectiveness and inadequacy of the current observing systems.
- Consider existing initiatives to identify EVs for different GEO SBAs.

The questions to be addressed included:

- To ensure that the indicators can be quantified, essential variables need to be identified and observed. What process and criteria could be used to identify EVs and link indicators to them?
- Is a top-down approach available and used to link indicators to EVs in your area of societal goals?

The question why EVs are needed was discussed and it was concluded that they are needed to:

- Understand natural and anthropogenic processes;
- Monitor state and trends in the Earth system;
- Detect and attribute changes;
- Assess the impacts of these changes;
- Identify tolerable limits of these changes (sustainable development).

Core criteria to select EVs were identified:

- Useful to a wide range of users, particularly decision makers;
- Cross-cutting several GEO SBAs;
- Credibility, Feasibility, Cost-effectiveness (GCOS criteria).

The discussion touched upon several aspects of EVs. EVs should be observable and useful at the same time. The usefulness of a variable potentially "essential" can be limited by uncertainty, resolution and accuracy. Therefore, in addition to them being essential for describing states and trends the EVs have to meet in practice the user needs. Could different EVs be used in different contexts according to different user categories, or should focus mainly be on "universal" EVs, cross-cutting different users and SBAs? This relates to the question who the main target users are for GEO, and the groups that were mentioned are policy makers and other high-level decision makers. A question that should be address at the ConnectinGEO workshop (scheduled for June 2015) on Essential Variables what that of what the current gaps are and the main requirements to set up operational monitoring networks.

Summarizing the main points of the discussion,

- EVs are currently probably more closely linked with the science community, while indicators are more relevant to the policy arena.
- EVs have been developed by various communities (IGOS, GCOS, Communities of Practice, GEO tasks, etc.).

- UN process has developed indicators to monitor progress toward the targets associated with the SDGs.
- Challenge is to connect all the dots in a more complete picture of how GEO can support SDGs.

For the path forward, the following points were noted:

- Gather the Evs from their respective arenas, including from organizations that have no previous connection to GEO.
- Look at the SBAs and identify the major geophysical processes within each SBA.
- Map the variables to the geophysical processes; map the variables also to the indicators for the SDGs; see where the gaps are.
- Use the GCOS criteria for EVs [credible, feasible, cost-effective] by way of assigning weighting/priorities/urgency

Plenary Session 3: Monitoring and Foreseeing the Changes: The Role of Earth Observations

Co-Chairs: Paola Campus, Andiswa Mlisa

The session started with reports from the two previous breakout sessions delivered by Senay Habtezion and Kathy Fontaine, respectively. See the previous sections for details.

Paola Campus discussed aspects of monitoring change. She pointed out that the increase of world-wide communications in the last decades has increased the level of information about the threats associated to Global Change and asked whether this really has increased awareness and resilience. A crucial step towards the development of an effective plan for increasing resilience and supporting sustainable development is based on the adoption of a comprehensive and interconnected monitoring of all the phenomena and parameters which might help issue early warnings associated with significant environmental changes. Basic components for robust monitoring include synergetic technologies and networks recording in real-time all the areas at risk on our Planet; simultaneous data transmission to operational centers in near-real time; optimized data analysis to rapidly identify a risk increase; and data sharing. She emphasized the role of GEO and GEOSS in ensuring these aspects.

Roberto Azzolini used the example of monitoring the polar regions to analyze the need for monitoring and the role GEO and GEOSS could play. He stated that deep Changes are affecting the Polar Regions much faster than other regions. They can have widespread effects on environment and socio-economic activities on hemisphere scale. The fast environmental changes could affect the human society at a rate that could not be properly recovered. However, they may also create new opportunities for societal development that must be managed properly.

Understanding and predicting changes is crucial for managing appropriate mitigation measures. Polar regions show in advance and with a greater clearness the climate changes happening on the Planet. Several authoritative Arctic and Antarctic Organizations, representing wide sectors of science, are working to provide scientific priorities and guidelines. The IASC ICARP III and the SCAR Horizon Scan initiatives must be mentioned in this framework. However, these organizations mainly focus on regional issues.

A huge asset of well equipped scientific infrastructure and technologies to face Polar issues is already available along with a top-level scientific community. However, despite the increasing number of international networks and programs, many observations are still carried out at a national or regional scale.

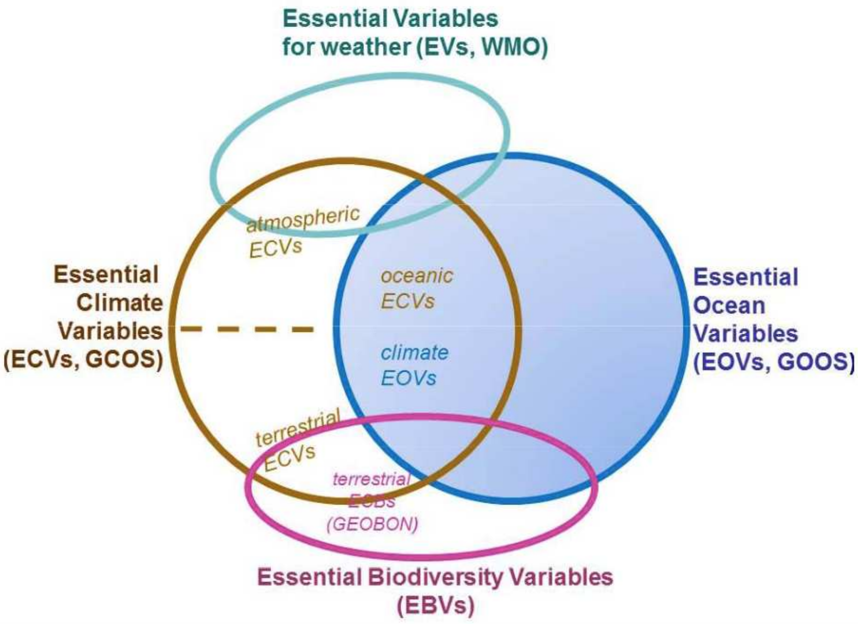


Figure 3. EVs for Different Domains and Their Overlap.
From Bourassa (2015), presentation at the workshop.

A rather high rate of fragmentation, duplication of efforts, not optimized use of infrastructures, scarcely coordinated national agendas and plans must still be faced.

In order to improve the eff ciency of the system, a common effort to strengthen cooperation supported by coordination, sharing infrastructure and data is needed. GEO should take into consideration the Polar Regions because of their vulnerability to changes and, at the same time, their crucial contribution to shape the Earth Climate and its changes. GEOSS may play a crucial role in integrating Polar observations at Regional and global scale and streamlining data sharing, interoperability and quality control.

He summarized that in close contact with polar organizations, programs and stakeholders GEO may help:

- Prioritize observation targets (EVs);
- Avoid fragmentation/duplication;
- Facilitate International Cooperation;
- Data Policy and Quality control.

Plenary Session 4: Setting Priorities

Chair: Wolfgang Grabs

The session was opened with a presentation by David Arctur on the GEOSS Water Services and their role in federating regional and national water data. He presented the activities in several AIP projects of the GEO Water SBA.

Mark Bourassa used the example of the oceans to discuss the community approach to EOVs.He pointed out that 93% of global warming is going into the oceans, and underlined that the oceans are en important sink for CO_2. They are also the dominant source of variability on time scales from weeks to centuries.

He showed that there is signif cant overlap between EVs for different domains (Fig. 3. In the climate and ocean communities, EVs have the following characteristics:

- Relevance: Important for monitoring the variability of the ocean or the climate system;
- Feasible: Technically able to measure at suff cient accuracy;
- Cost Effective: able to support the cost of the observations

Feasibility and Cost Effectiveness are also critical to get "buy in" from funders of the observing system (not just Relevance). He raised the question of who "owns" the EVs:

- Integrated Ocean Observing System (IOOS) Physical Variables:
  - salinity, temperature, bathymetry, sea level, surface waves, surface (vector) currents, ice concentration, surface heat f ux, bottom characteristics
  - IOOS Meteorological variables are covered by GCOS
- Global Ocean Observing System (GOOS) Physical Variables:
  - Based on Global Climate Observing System (GCOS) Ocean variables
- Related GCOS Ocean Variables:
  - Surface: Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Surface current, Ocean colour, Carbon dioxide partial pressure, Ocean acidity, Phytoplankton.
  - Subsurface: Temperature, Salinity, Current, Nutrients, Carbon dioxide partial pressure, Ocean acidity, Oxygen, Tracers

Another question considered by the speaker was "How do we def ne accuracy requirements?"

- One approach is to take requirements for different applications:
  - Example, the *Rolling Repository of Requirements (RRR)* available at https://www.wmo.int/pages/prog/www/C DB.html
  - However, there are many applications and conf icting input:
    - Operations?
    - Science?
- Alternatively, requirements can be determined for processes:
  - Estimate the accuracy needs. Sampling based on time scale
  - Perhaps 10 times the sampling is needed to understand
  - Allows quantitative assessment of f tness for purpose for each purpose
  - Provides researchers with information about what can be achieved with the existing and historical observation systems

Mark Bourassa summarized the talk with the following points:

- There are multiple sets of EOVs depending on the organization that states what is essential. ECVs are def ned by one group (GCOS)
- We are trying to better articulate the links between SBAs, science issues, observational requirements and EVCs
- The Framework for Ocean Observations (FOO) and Strategic Mapping provides a mechanism for feedback between SBAs and ECVs and feedback to modify the requirements and ECVs
- Goals for the observing system f t well into this context
- One of the great lapses is sustaining observations

Joint Plenary Session A: Changing Science for a Changing Planet

Co-Chair: Hans-Peter Plag, James Syvitski

Dork Sahagian opened the session with a keynote addressing the relationship of science and society, asking whether it is symbiotic or askew. He pointed out that science was initially developed to address societal needs and developed to serve an evolving society. In the 20th century, scientists started to serve industry. In the 21st century, scientists face greater challenges due to a rapid global change, and they have to evolve into planetary physicians (Fig. 4). He identif ed four types of questions that science needs to address:

- Analytical questions: What do we need to know about the basic science issues?
- Operational questions: How should we proceed with adaptation and mitigation?
- Normative questions: What do we want?
- Strategic questions: Ho do we get what we want?

He pointed out that IGBP/GAIN had identif ed a total of 23 questions in the categories that need to be addressed by the science of the 21st century. He identif ed contradictions between individual goals (e.g., the contraction between “eradicate poverty” and “halt climate change”). Emphasizing that science cannot solve the problem and that only people can do this, he added a few questions to be considered in the deliberations:

- What kind of natural, social, and economic environments do we want for ourselves and our great-grandchildren?
- What equity principles should be used for resource allocation?
- Who should assume the risk (and cost) for known hazards?
- Who should control policy decisions? What role should science (and scientists) play?

Sketching the way forward, he emphasized the importance of organizing and articulating societal goals; strengthening the scientif c community; promoting short and long-term research; and couching scientif c results in societal terms. He concluded that the role of science has changed in the 21st century, because humanity must learn to “live off the interest” provided by the global ecosystem. In order to achieve this societal goals must be clarif ed and science must address them. Moreover, scientists must speak the

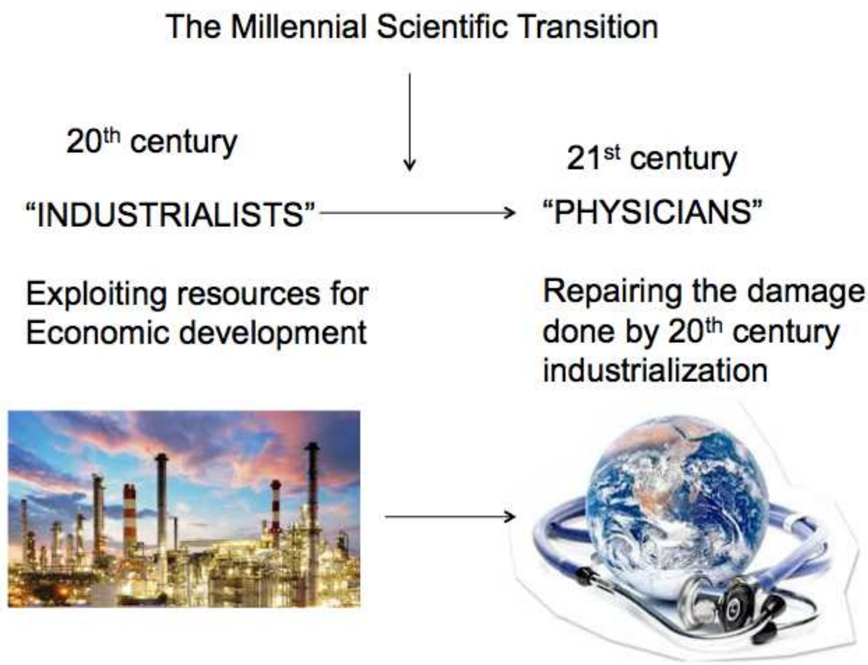


Figure 4. The Millennial Scientif c Transition.
In the 20th century, scientists played a crucial role in supporting the industrial development that was based on exploiting resources for economic development. In the 21st century, the role of scientists has to transition to that of planetary "physicians" engaged in repairing the damage done in the 20th century.

language of society (not vice-versa), and society needs to acknowledge that science is a critical part of society, not an adversary.

Dennis Oijma summarized the scope and objectives of "Future Earth." He identif ed the complex challenges in the Anthropocene as:

- Feeding nine billion people within planetary boundaries
- Understanding ocean and coastal transitioning under changing climate and biodiversity conditions
- Adapting to a warmer and more urban world
- Reducing disaster risks
- Valuing and protecting natures services and biodiversity
- Providing income and innovation opportunities through transformations to global sustainability
- Improving equity
- Estimating wealth and well-being, not GDP
- Aligning governance with stewardship

Future Earth is assisting with research in support decision making for UN Conventions (UNFCC, CBD, UNCCD) and SDGs by supporting discovery and innovation to address the demands and requirements of evidenced based decisions. In a vision for 2015, he identif ed the challenges:

- Nexus of Sustainable water, energy, and food systems
- Low carbon socio-economic systems
- Safeguard the terrestrial, freshwater and marine natural assets
- Build healthy, resilient and productive cities
- Promote sustainable rural futures
- Improve human health by understanding complex environmental interactions
- Encourage sustainable consumption and production patterns
- Increase social resilience to future natural threats

Stefano Nativi discussed the next technological revolution for the *GEOSS Common Infrastructure (GCI)*. He acknowledge that in the past 10 years, GEO has done valuable work in building GEOSS. By recognizing and embracing significant technological revolutions, GEOSS has increased the discoverability and accessibility of data and services. Flexibility and openness are important to assure further evolution. He predicted that the next revolution will require to develop a cloud-based software ecosystem, and a social ecosystem to create and share a knowledge base.

Hans-Peter Plag reviewed the challenges for humanity resulting from the transition into the Post-Holocene. The changes introduced to the Planet in terms of energy usage, land use, population growth, biodiversity loss, and climate change are pushing the coupled natural and socio-economic system out of the SOSH that the Holocene has provide to humanity. In this transition, it will be important to detect any approach to major thresholds as early as possible. He showed that the climate system is outside the normal range defined by the variability during the last 800,000 years, and the prognosis is putting the system far away from that normal range. Referring to Tim Lenton's earlier presentation, he emphasized the importance of thresholds and crossing these might change the system substantially. He asked whether a science that is more focused on avoiding Type 1 errors (basically false alarms) that Type 2 errors (basically missed alarms) can provide the knowledge that decision makers need to understand the scale of the challenge this transition has and the timely warnings needed to avoid global disasters in the course of the transition.

James Syvitski started with the statement that in the 21^{st} century, the three pillars of environmental cyber-infrastructure are: 1) satellite observations, 2) field observations, and 3) model simulations. His presentation focused on the last of these, and he used three examples to illustrate the power of model simulation:

- Application of nested and coupled models used to assess the role of hurricanes on offshore infrastructure.
- Using coastal deltas, where surface elevation change is complex, involving crustal motion, climate and runoff, vegetation dynamics, sedimentation, sediment compaction, and sediment transport, by waves, tides and currents, he demonstrated the use of models to assess the importance of environmental processes and parameters.
- Use of models to assess the risk and predict river floods.

The comparison of model simulations and predictions to in situ and remote sensing observations highlighted the importance of all three pillars of 21^{st} century environmental cyber-infrastructure.

The discussion at the end of the session emphasized the challenges for both science and society that results from global and climate change. The role of GEO and GEOSS within the three pillars of environmental intelligence discussed by James Syvitski was underlined.

Joint Breakout Sessions: Creating the practice-relevant knowledge to cope with global change

The breakout sessions reviewed methods for knowledge creation related to key areas of global change and consider the possibilities of rapid changes that might challenge the traditional scientific approach.

Joint Breakout Session 1: Intelligent use of data quantity vs focusing on data quality

Chair: Stefano Nativi; Rapporteur: Bart de Lathouwer

The new Web 2.0 environment has impacted economy with what is termed "wikinomics" by Don Tapscott and Anthony Williams and shifted the basis to four principles: openness, peering, sharing and acting globally. Stefano Nativi introduced the questions to be addressed in the session: How is the Web 2.0 impacting the generation and use of data and knowledge? How can, and how should, classical Earth observation with a focus on data quality make use of the new technologies where the data quantity provides for new ways of extracting information and knowledge from the huge amount of data available now? How can new approaches of co-design of research agendas for problem solutions and co-creation of knowledge help make use of data quantity?

Bart De Lathouwer introduced the *Open Geospatial Consortium (OGC) Web Processing Service (WPS)* as a tool that functions as a filter for the web, similar to the "Unix filter". It allows definition of web work flows for complex analyses. It also provides the utility to upload the processing into the cloud and down-load the result instead of down-loading all data that is stored in the cloud for local processing.

Jonas Eberle discussed requirements for intelligent use of large data quantity and identified automation in data access, easy to use clients, and the utility to create and publish new information as core ingredients. Important goals of using the data include the detection and attribution of change. For that, the scientific algorithms have to be linked to automated data access. For an "Earth Change Monitor" he stated the objectives as:

- Detect areas based on environmental change events in high density time series data (MODIS);
- Provide high resolution images (Landsat) of the pre- and after change events;
- Add further datasets to distinguish between different types of change;
- Provide simple tools for users and developers with web services and web interfaces.

The Earth Change Monitor makes use of a wide variety of available data (data quantity) to create new information, which is used to build up a reference database. He concluded that crowd-sourced initiatives can help scientists to better test their algorithms for information extraction and benefit from the input of users. He emphasized the need for simple web services for data access linked with web services for algorithm execution registered in GEOSS.

Palma Blonda discussed the role of expert knowledge for the integration of in situ and remote sensing data using the example of habitat and ecosystem monitoring. Multi-source data integration plays a crucial role for the monitoring. A knowledge-based world model (in a specific domain) consists of concepts (objects) and spatial and temporal relationships between these objects. Ontologies play a core role in describing the relationships.

Joint Breakout Session 2: Shifting from disciplinary to problem and solution focused science

Chair: Kathy Fontaine; Rapporteur: Andiswa Mlisa

The complexity of global change, climate change, and sustainability requires a transition from a bottom-up, discipline-based approach that often addresses complexity by simplification, to a top-down approach starting at the problem and recognizing the full scale of complexity. Kathy Fontaine opened the session by reminding that research generally categorized into "basic (pure)" and "applied" research. The basic research can be broken into theoretical and experimental/practical, and seeks to add to the general body of knowledge. The applied research seeks to solve a specific problem. While basic research is generally funded by a governmental institution for the public good, applied research is generally funded by private Research and Development entities. However, lately there is a tendency for governmental institutions seeking to prove return on investment by funding more applied-type research in support of solving policy problems. Given the trend to use basic research results for applied research problems, and given that GEO focuses on providing the results of basic research for use in the applied sciences, she asked the session participants to consider the following questions:

- What recommendations can we make to facilitate the reuse of basic research data in support of SDGs, SBA goals, etc.?
- What might the implications be for modeling, reproducibility, ethics, and other research data sharing and reuse concerns?
- Are there any communities that have models we can study (for instance, the clinical trial model)?

In the discussion, it was underlined that there is a need to start with end users, incorporate the decision makers from the beginning of the projects, and tailor the delivery of science into the application. This should be a requirement for the composition of the GEO Flagships and Initiatives. These components need to understand how decisions are made and the data and information needs to be packages to be fit for the purpose.

The Research community was identified as a user community. There needs to be a balance between the needs of the research community and operational requirement resulting from other user groups. GEO also needs to address the issue of trust in applications from the various communities. A question to consider is how to shape GEO so that it involves a bigger constituency, and also involves this community in the Flagships and even the the Ministerial Summits.

It was recommended that national GEO representatives engage with the statistical agencies with respect to the EO contribution to the indicators for the SDGs. This would also help to ensure inclusion of environmental data for the monitoring of the SDG targets. GEO should consider a role in setting targets and defining indicators.

It was suggested that best practices are developed for showcasing how data, technology and communities move from basic to applied research. This would support the dialogues with users. Considering a recipe or blue print for a good case study would allow reusing it for other applications. Points to consider include:

- Provenance, work flow, transformational algorithms, political issues
- Impact on the decision with or without the EO information

The GEOSS Knowledge Base could be a place to store this information and GEO should maintain the information as part of a Foundational Tasks.

There was considerable discussion on what openness means in the various communities and within GEO:

- Open access to data and interoperability;
- Data integrity; traceability of what happens to data;
- Open access and sharing of the data could mean not everything is open at the back end;
- What are the implications of processing the data in cloud or by the DAB, can the provided softwares be trusted?
- Linkage between access to data and time frames for decision making (e.g., climate change happens so quickly that we need the research data to be freely available)

Joint Plenary Session B: Linking Societal Goals, Science, Metrics, and Observation Systems

Co-Chairs: Stefano Nativi, Hans-Peter Plag

In the final session, the rapporteurs of the previous two breakout session presented their report (see previous sections for details).

The final presentation was given by Bruce Wielicki, who started by pointing out that there is no climate observing system. The meteorological observing system is a weather observing system, which does not provide the very accurate climate data. Based on an extensive model study, he concluded that climate requires ten time the amount of data and a ten time higher accuracy than weather. Because of the lack of a climate observing system, knowledge about climate change is uncertain, and this uncertainty leads to inaction. Although the necessity of monitoring and understanding anthropogenic climate change was acknowledge in the late 1970-ties, thirty five years later the "climate change building" is still in a poor shape (Fig. 5).

The climate modeling community is struggling to get sufficient resources for the modeling. As a result, science questions related to climate change are typically qualitative not quantitative, focusing more on the understanding and exploring than the rigorous testing of hypothesis. The resulting uncertainty in climate change leads to inaction, which has a high cost in the future. The cost of business as usual was estimated to be on the order of 0.5 to 5% of the global GDP in the 2050 to 2100 window. He asked the question, "What is the right amount to invest in climate science?" Answering this question requires the linking of science to economics and a thinking outside narrow disciplines. Based on thousands of model runs, the economic assessment showed that even investing an additional $10 B/year over the next 30 years for a climate observing system would lead to a large return of investment. He criticized the absence of long-term commitment for climate observations (Fig. 6).

He recommended a transition to quantitative science questions focusing on rigorous hypothesis testing and the conduction of observing system simulation experiments to improve the observation requirements for these systems. He pointed out that at current pace, its seems unlikely that climate change will be understood much better even after another 35 years. Underlining that we cannot go back in time and measure what we failed to observe, he ended by stating that It is time to invest in an advanced climate observing system.

The final discussion focused on the importance of a comprehensive observations system that can produce the environmental intelligence required by the global governments to ensure a sustainable development and progress towards the SDG targets. The roles of GEO in this effort included an convening role linking the users of EOs with the providers in an effort to better capture the societal information needs and to meet these needs with users focused data and information products.

35 Years Later …

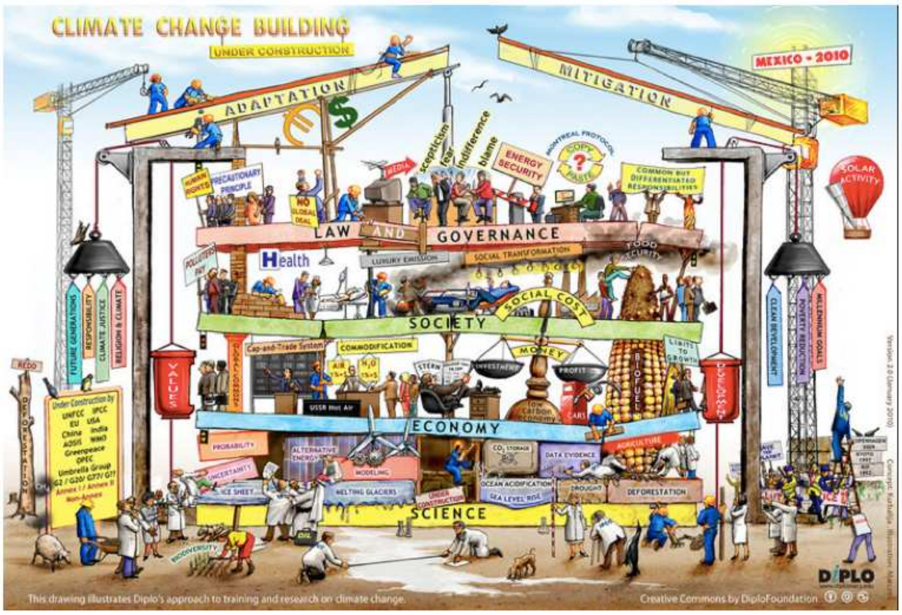


Figure 5. The Climate Change Building.
Thirty five years after it was acknowledge that monitoring and understanding anthropogenic climate change is an important task for humanity and at a time when it is clear that this is even more urgent, the "climate change building" is still in a poor shape. From Bruce Wielicki's presentation.

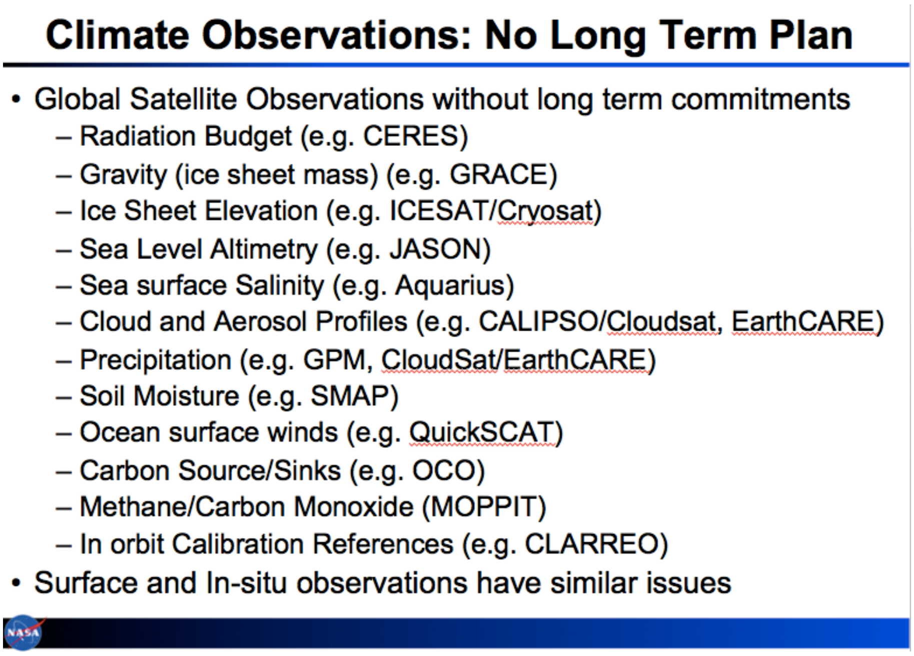


Figure 6. The Lack of Long Term Commitment for Climate Observing Satellites.
For many satellites that are crucial part of the climate observing system, a long-term commitment is lacking. Similarly, surface and near-surface observations face similar issues. From Bruce Wielicki's presentation.

4.5 Workshop Program

Monday, March 23, 2015

0800 - 0900:	*Registration*
0900 - 1030:	Plenary Session 1: Assessing and Managing the Changes: The Metrics Co-Chairs: *Hans-Peter Plag, Stefano Nativi*
0900 - 0910	*Douglas Cripe, Geo Secretariat*: Welcoming Address
0910 - 0920	*Hans-Peter Plag, Stefano Nativi*: Workshop Organization and Goals
0920 - 0950	*Douglas Cripe*: The GEO Strategic Plan for 2015-2025
0950 - 1020	*Tim Lenton*: Keynote Presentation: Measuring Global Changes and Detecting Tipping Points
1020 - 1030	*Workshop Chairs*: Mission for Breakout Sessions
1030 - 1100:	*Coffee Break*
1100 - 1230:	Breakout Sessions Block 1: Designing the Metrics
	Breakout Session 1.1: Sustainable Development Goals, Global Boundaries, and Safe Operating Space for Humanity Chair: *Hans-Peter Plag*; Rapporteur: *Senay Habtezion*
1100 - 1120	*Hans-Peter Plag*: Introduction to the session
1120 - 1220	*All*: Discussion
1220 - 1230	*Hans-Peter Plag, Senay Habtezion*: Session Summary
	Breakout Session 1.2: GEO Societal Benefit Areas Chair: *Antonio Bombelli*; Rapporteur: *Mark Bourassa*
1100 - 1115	*Antonio Bombelli*: Introduction to the session
1115 - 1220	*All*: Discussion
1220 - 1230	*Antonio Bombelli, Mark Bourassa*: Session Summary
1230 - 1400:	*Lunch*
1400 - 1530:	Plenary Session 2: Assessment of the Metrics Chair: *Jay Pearlman*
1400 - 1405	*Jay Pearlman*: Introduction to Session
1405 - 1415	*Senay Habtezion*: Report of Breakout session 1.1
1415 - 1425	*Mark Bourassa*: Report of Breakout session 1.2
1425 - 1500	*Ben Hamlington*: Keynote: What we know and don't know about sea level
1500 - 1530	*Toste Tanhua*: Keynote: Indicators and Essential Variables
1530 - 1535	*Workshop Chairs*: Mission for breakout sessions
1535 - 1600:	*Coffee Break*
1600 - 1730:	Breakout Sessions Block 2: Quantifying the Metrics
	Breakout Session 2.1: Essential Variables for Sustainable Development Goals, Global Boundaries and Safe Operating Space for Humanity Chair: *Hans-Peter Plag*; Rapporteur: *Senay Habtezion*
1600 - 1615	*Hans-Peter Plag*: Introduction to the session
1615 - 1720	*All*: Discussion
1615 - 1730	*Hans-Peter Plag*: Session Summary
	Breakout Session 2.2: Essential Variables for GEO Societal Benefit Areas Chair: *Antonio Bombelli*; Rapporteur: *Kathy Fontaine*
1600 - 1615	*Antonio Bombelli*: Introduction to the session
1615 - 1630	*Douglas Cripe*: Essential Variables in the Water SBA
1630 - 1730	*All*: Discussion

Tuesday, March 24, 2015

0800 - 0900:	*Registration*
0900 - 1030:	Plenary Session 3: Monitoring and Foreseeing the Changes: The Role of Earth Observations Co-Chairs: *Paola Campus, Andiswa Mlisa*
0900 - 0910	*Senay Habtezion*: Report of breakout session 2.1
0910 - 0920	*Kathy Fontaine*: Report of breakout session 2.2
0920 - 0940	*Paola Campus*: Introduction to Monitoring of Changes
0940 - 1010	*Roberto Azzolini*: Keynote: Monitoring the polar regions
1010 - 1030	*All*: Discussion
1030 - 1100:	*Coffee Break*
1100 - 1230:	Plenary Session 4: Setting Priorities Chair: *Wolfgang Grabs*
1100 - 1130	*David Arctur*: Keynote: GEOSS Water Services: Federating Regional and National Water Data
1130 - 1200	*Mark Bourassa*: Keynote: Key essential variables: The example of the oceans
1200 - 1230	*All*: Discussing the priorities
1230 - 1400:	*Lunch*
1400 - 1730:	Joint Plenary Session A: Changing Science for a Changing Planet Co-Chair: *Hans-Peter Plag, James Syvitski*
1400 - 1430	*Dork Sahagian*: Keynote: Science and Society: Symbiotic or Askew?
1430 - 1500	*Dennis Oijma*: Keynote: Future Earth Research Challenges
1500 - 1530	*Stefano Nativi*: Keynote: The Next Revolution for the GEOSS Common Infrastructure
1530 - 1600:	i*Coffee Break*
1600 - 1630	*Hans-Peter Plag*: Keynote: The Need For A New Science to Guide Humanity's Transition Into The Post-Holocene
1630 - 1700	*James Syvitski*: Keynote: Use of Surface-Dynamic Models for Identifying Environmental Indicators and Processes
1700 - 1725	*All*: Discussion
1725 - 1730	*Session Chairs*: Mission for the breakout sessions

Wednesday, March 25, 2015

0900 - 1030:	Joint Breakout Sessions: Creating the practice-relevant knowledge to cope with global change
	Joint Breakout Session 1: Intelligent use of data quantity vs focusing on data quality Chair: *Stefano Nativi*; Rapporteur: *Bart de Lathouwer*
0900 - 0905	*Stefano Nativi*: Introduction to the breakout session
0905 - 0920	*Andreas Matheus*: The COB-WEB Project
0920 - 0935	*Bart De Lathouwer*: Use of WPS (and other web services) for Earth Observation
0935 - 0950	*Jonas Eberle, Christian Hüttich, Christiane Schmullius*: Automatization of information extraction to build up a crowd-sourced reference database for vegetation changes
0950 - 1005	*Palma Blonda, C. Marangi, A. Adamo, C. Tarantino, F. Lovergine*: Integration of EO and in-situ data through expert knowledge for habitats and ecosystems monitoring
1005 - 1020	*Dave Jones*: The Challenge of accessing and Sharing “Big Data” in Real-Time – Connecting GEO Nations Now
1020 - 1030	*Stefano Nativi, Bart de Lathouwer*: Session Summary
	Joint Breakout Session 2: Shifting from disciplinary to problem and solution focused science Chair: *Kathy Fontaine*; Rapporteur: *Andiswa Mlisa*
0900 - 0915	*Kathy Fontaine*: Introductions to the breakout session
0915 - 1020	*All*: Discussion
1015 - 1030	*Kathy Fontaine, Andiswa Mlisa*: Session Summary
1030 - 1100:	*Coffee Break*
1100 - 1230:	Joint Plenary Session B: Linking Societal Goals, Science, Metrics, and Observing System Co-Chairs: Stefano Nativi, Hans-Peter Plag
1100 - 1115	*Bart de Lathouwer*: Report from joint breakout session 1
1115 - 1130	*Andiswa Mlisa*: Report from joint breakout session 2
1130 - 1200	*Bruce Wielicki*: Keynote: Climate Change Accuracy: Observing Requirements and Economic Value
1200 - 1230	*All*: Discussion

4.6 Abstracts

GEOSS Water Services: Federating Regional and National Water Data

David Arctur, University of Texas at Austin

Since 2012, the Water SBA team for the GEOSS Architecture Implementation Pilot (AIP) has helped water data agencies in several countries to implement and publish standards-based water resource information. The following water data providers and research centers have developed a consistent implementation of this framework, which are or will soon be searchable in GEOSS:

- CUAHSI Water Data Center - collecting water data from over a hundred data providers
- Canadian Rainfall Monitoring Network - precipitation
- Flemish Water Portal (Belgium) - streamf ow
- French Geological Survey (BRGM) Groundwater Level Monitoring Network
- Italian National Water Agency (ISPRA) - streamf ow
- New Zealand National Water Agency (NIWA) - streamf ow, temperature, and 9 water quality variables
- Taiwan Monitoring Network - streamf ow
- USGS National Water Information System (NWIS) - streamf ow
- NASA Land Data Assimilation System (LDAS) - model-based time series ("data rods") for global precipitation, runoff, soil moisture, evapotranspiration, and other land surface dynamics variables.

Continued development and expansion of this network will bring within reach the ability to study and understand water data across and among whole continents, on demand.

The emphasis in the upcoming 2015 cycle will be the application of this GEOSS Water Services framework for f ood monitoring, prediction, and mitigation.

Integration of EO and in-situ data through expert knowledge for habitats and ecosystems monitoring

P. Blonda, C. Marangi, A. Adamo, C. Tarantino, F. Lovergine

Expert knowledge can be used to develop a descriptive scheme, based on ontologies, of habitats (as proxies for species), ecosystems, ecosystem services and their interactions/functions and related Indicators and variables such as Essential Biodiversity Variables (EBV), Essential Ecosystem Variables (EEV).

The main objective is to design and develop a pre-operational cost-effective environmental monitoring system able to integrate EO and in-situ data, based on the elicitation of such knowledge. The system should provide as outputs series of thematic maps (LCLU and habitats, ecosystems, with these based on MAES report def nition) and extract indicators and essential variables (EV) to be used as inputs to change detection and modelling tools. The experience developed in the FP7 BIO_SOS project will be described as basis for future research within the Horizon2020 Ecopotential project.

Essential Observations for the Oceans

Mark A. Bourassa, Center for Ocean-Atmosphere Prediction Studies, Florida State University, Tallahassee, FL Co-chair Ocean Observation Panel for Climate

The ocean observations that are deemed (by national and international organizations) as important and feasible to observe with sufficient accuracy as Essential Climate Variables (ECVs) or as Essential Ocean Variables (EOVs). These variables have been well established for physical oceanography, and some have been established for the biogeochemistry. The biological community is working towards suggesting EOVs to the national and international organizations that are charged with selecting these variables and setting the observational goals. Decades ago, the physical oceanography, atmospheric, and terrestrial ECVs were determined with the goal of addressing climate variability in the context of societal issues and related science questions. The Essential Ocean Variables were developed later, with goals beyond climate: weather forecasting, transport, recreation and others. They are similar to the ECVs, but also address issues such as the delay between observations being taken and being made available, as well as the differences in quality between near real-time data and delayed mode data (which often has more rigorous quality control and adjustments to improve accuracy). A short overview of ECVs and EOVs will be given, with a short explanation of some of the differences. Efforts are ongoing to better select and explain the need for ECVs and EOVs. Therefore this is a time when outreach and interaction will have their maximum benefit.

A question that is currently being pondered is how to take advantage of established components of the observing system (typically physical variables) to more rapidly develop and deploy less mature components of the observing system (chemical and biological variables). Key issues are structural compatibility and changes in cost, operational life time, and infrastructure needs. For example, the cost and availability of ship time influences the goals for operational lifetime. The sampling needs and the advantage of collocated variables is another critical consideration. For example, the usefulness of many biogeochemical variables is greatly enhanced by collocation with physical variables, and vice versa. Another factor in considering how these observations should be combined is the links to societal and science drivers, which are in turn linked to global conventions and mandates. New efforts to describe these links will be described and demonstrated. The approach shown highlights the different applications to which the observations apply.

Automatization of information extraction to build up a crowd-sourced reference database for vegetation changes

Jonas Eberle, Christian Hüttich, Christiane Schmullius; Friedrich-Schiller-University Jena, Institute for Geography, Department for Earth Observation, Jena, Germany

Scientists can benefit from the wide range of data quantity if their algorithms are made available to the public in an easy-to-use manner. Automated data access in combination with the follow-up execution of algorithms can help to test algorithms in different regions around the world and lead to new information based on the knowledge of local users. In the example of vegetation change analysis based on Earth Observation time-series data, we can provide lots of data for the validation of changes detected by scientific algorithms, e.g., true/false color images, fire data, weather data. Based on these input users can validate the algorithm in their study areas. Furthermore, they can build up a database with change areas that can be used as reference databases on other analysis tools (e.g., change classifications).

Based on the bfast (Breaks For Additive Season and Trend) algorithm we can detect vegetation changes in time-series data. For the validation of a detected "break" we will search automatically for other datasets at the detected date of break and provide these data in an easy-to-use web portal. So users can execute the algorithm for change detection and validate the detected changes. A crowd-sourced reference database can be build up on areas where change occurred and this change was validated by users.

Such a crowd-sourced initiative can help scientists to better understand algorithms for information extraction. The authors of an algorithm can benef t from the input of users that are testing the algorithm. The Web 2.0 leads us to a new way of how algorithms can be tested and how we can build up reference databases with areas around the world. Thus, Earth Observation time-series data are better useable and lead to new knowledge to further improve algorithms and validated reference information.

In this presentation the author will describe the developments made for automated data access in combination with automated data analysis based on Earth Observation vegetation time-series data with no need to process any data by the users.

What We Know and What We Don’t Know About Sea Level

Benjamin Hamlington, Center for Coastal Physical Oceanography, Old Dominion University, Norfolk, VA, USA

The change of sea level in response to the warming of our planet is of great interest for both scientif c and socio-economic reasons. Sea level change has enormous socio-economic implications for the planet as coastal populations become more susceptible to storm surges and eventually inundation from the oceans. In addition, sea level is an essential climate variable and critical indicator of how our planet is responding to climate change. Sea level, when averaged globally, responds primarily to the amount of heat absorbed by the oceans, and the melting of land ice. Thus, many groups—climate scientists, politicians, economists, insurance companies, public utilities, coastal property owners, civil engineers, and other “stakeholders”—have a need for accurate and reliable projections of future sea level change and its regional variations.

Projecting sea level change begins with improving our understanding of past sea level change and the factors contributing to it. On a local level, the sea level problem is complex due to its multi-facetted and coupled nature, involving essentially all Earth System components, and including multiple feedbacks. In the past decade, the network of observing systems has grown to be able to measure more of the factors contributing to sea level than ever before. This has led to signif cant advances in our understanding of sea level change in the past, present and future, while also aiding model efforts to project future regional sea level rise. Despite this, signif cant gaps in our understanding remain that have important implications for our ability to prepare for climate change in the coming years. In this presentation, we take stock of what we currently know and what needs to be understood better regarding sea level rise on global and regional scales. Although the focus is on sea level, the discussion here can be similarly extended to other areas, underscoring the need for improved understanding of all essential climate variables.

Anticipating tipping points

Tim Lenton, Earth System Science, University of Exeter, Exeter, U.K.

A tipping point occurs when a small change in forcing triggers a strongly non-linear response in the internal dynamics of a system, qualitatively changing its future state. Large-scale tipping elements have been identif ed in the Earths climate system that may pass a tipping point under human-induced global change this century (Lenton et al. (2008) PNAS 105: 1786-1793). Such abrupt, non-linear changes are likely to have large impacts, but our capacity to forecast them has historically been poor. Recently, much excitement has been generated by the possibility that approaching tipping points carry generic early warning signals (Scheffer et al. (2009) Nature 461: 53-59; Lenton (2011) Nature Climate Change 1: 201-209). I will introduce the theory and prospects for gaining early warning of approaching climate tipping points.

Promising methods are based on detecting critical slowing down in the rate a system recovers from small perturbations, and on characteristic changes in the statistical distribution of its behaviour (e.g. increasing variability). Early warning signals have been found in paleo-climate data approaching past abrupt transitions, in models being gradually forced past tipping points, and in analysis of recent Arctic climate data. I will discuss the outstanding challenge of how to design a tipping point early warning system and how to identify the essential variables to monitor in specific target systems.

The Next Revolution for the GEOSS Common Infrastructure

Stefano Nativi, Institute of Atmospheric Pollution Research of the National Research Council of Italy (CNR-IIA), Sesto Fiorentino, Italy

GCI has faced some important (technological) revolutions in the past 10 years. Entering in its next decade, GEOSS and the GCI are going to face a new important revolution, including Pico satellites and Internet of Things, Big Data Analytics and Knowledge generation, Citizen Observatories and Consumerization. This presentation will introduce the present GCI architecture, discussing its flexibility and introducing its possible extension to address the next challenges.

Future Earth Research Challenges

Dennis Ojima, Colorado State University, US Global Hub of the Future Earth Executive Secretariat, School of Global Environmental Sustainability, Fort Collins, CO, USA

The primary mission of Future Earth is to align the global change research community with decision makers and innovators of change to co-develop pathways for sustainable development and transformation to sustainability. Future Earth provides a platform to analysis and development of strategies to enhance resilience and preparedness to global change in regions and ecosystems across the globe. Future Earth has enhanced trans-disciplinary research and engagement activities across a suite of issues (e.g., food security, energy, public health, water, biodiversity loss) and public and private sector partners related to development, risk reduction, and strategies to more sustainable use of ecosystem services and natural capital.

Regional to global research across multiple sectors will require greater integrated observations platforms and analysis tools. Inter-operability across and between earth system parameters and societal information will be needed to provide decision makers in the public and private sector the knowledge needed to make science based decisions on assets being managed. Current global tools provide aggregate analysis of certain aspects of the earth system, however greater granularity of integration and analysis will be necessary for management decisions by regional to local decisions makers.

Social-ecological systems which bring together observations and analysis of multiple capital ranging from natural capitals to social, physical, and institutional capitals will provide an integration platform of information and knowledge. Developing this information for decision making will need to provide the information at the scale and metrics used currently by decision makers. The translation of observations and analysis will need to be co-designed with various sectors and end-users. Further research and innovation will be needed to finalize the co-production of information useful to these end-users.

Future Earth will focus on the societal challenges identified in the 2015 Vision report and utilize these to aggregate the various SDG indicators across these 8 different domains of interest to Future Earth. The eight Challenges are to:

- Deliver water, energy, and food for all, and manage the synergies and trade-offs among them, by understanding how these interactions are shaped by environmental, economic, social and political changes.

- Decarbonise socio-economic systems to stabilise the climate by promoting the technological, economic, social, political and behavioural changes enabling transformations, while building knowledge about the impacts of climate change and adaptation responses for people and ecosystems.
- Safeguard the terrestrial, freshwater and marine natural assets underpinning human well-being by understanding relationships between biodiversity, ecosystem functioning and services, and developing effective valuation and governance approaches.
- Build healthy, resilient and productive cities by identifying and shaping innovations that combine better urban environments and lives with declining resource footprints, and provide efficient services and infrastructures that are robust to disasters.
- Promote sustainable rural futures to feed rising and more affluent populations amidst changes in biodiversity, resources and climate by analysing alternative land uses, food systems and ecosystem options, and identifying institutional and governance needs.
- Improve human health by elucidating, and finding responses to, the complex interactions among environmental change, pollution, pathogens, disease vectors, ecosystem services, and peoples livelihoods, nutrition and well-being.
- Encourage sustainable consumption and production patterns that are equitable by understanding the social and environmental impacts of consumption of all resources, opportunities for decoupling resource use from growth in well-being, and options for sustainable development pathways and related changes in human behaviour.
- Increase social resilience to future threats by building adaptive governance systems, developing early warning of global and connected thresholds and risks, and testing effective, accountable and transparent institutions that promote transformations to sustainability.

The Need For A New Science to Guide Humanity's Transition Into The Post-Holocene

Hans-Peter Plag, Mitigation and Adaptation Research Institute, Old Dominion University, Norfolk, VA, USA; Shelley Jules-Plag, Tiwah, USA

Humanity has left the Holocene and the "safe operating space for humanity" it provided to us. The Holocene, the last geological epoch that began about 11,700 years ago, had an exceptionally stable climate that allowed human beings to settle in one place for a long time and to learn agriculture. With 6,000 years of a stable sea level humans were able to build long-term settlements in river deltas and benefit from the rich ecosystem services and logistical advantages of being at a river and the coast.

During the last hundred years, many things have changed very rapidly: we grew in numbers several hundred times faster than ever before, our energy usage grew 1,600 times faster, and inequality among humans grew 100 times faster. These rapid changes led to an increase of atmospheric carbon dioxide about 600 times faster than during the Holocene, temperature changed more than 100 times faster, and extinction rates of at-risk species increased dramatically. While we have seen many environmental factors changing rapidly, others are lagging behind and will soon exhibit accelerated changes. Sea level in particular has the potential to rise rapidly and threaten our global society.

We have replaced the time of stability by a time of rapid change, making the future for our children very uncertain. The planet is on a trajectory that is rapidly moving us away from the safe operating space. We discover thresholds normally (with a few exception) by crossing them. The rapid degradation of the Earth's life support system resembles the situation of a patient in the emergency room with rapidly degrading organs. The best news out of the emergency room is that the patient is stable, and the on-going changes within humanity and in the Earth's life-support system do not signal that this is the news about humanity in the emergency room.

Safeguarding the future requires a major paradigm shift in which we work towards slowing down these rapid changes so that we can reach a new equilibrium with the planet and it's life-support system. Our economy needs to safeguard the Earths life-support systems on which we and all future generations depend, instead of aiming for more wealth for a few. Our goal needs to be equity among humans both in time and space.

Current science is not explicitly focusing on the knowledge needs that arise from this existential challenge to reach equilibrium and restore stability. If such knowledge emerges, it is a bi-product. We do not have a science adapted to being in the emergency room, and while there are emerging research activities that aim to find ways for humanity to thrive without degrading the Earths life support systems, there is no strategic science framework that would bring these initiative coherently into a major effort of humanity to generate the knowledge we need to meet the challenge. There is also a need for a coupled tactical science that could respond to rapidly developing new threats, which we should expect as a consequence of the rapid changes we are enforcing on the system that supports our life. With such a framework, science could generate the knowledge to be integrated into decision making for a safe journey into the uncertain future of the Post-Holocene. Like in the emergency room, having the observing system that provides comprehensive information about the states and trends of the both humanity and the life-support systems is crucial for global governance to make informed decisions how to react to rapid changes and new developments.

Science and Society: Symbiotic or Askew?

Dork Sahagian, Earth and Environmental Sciences, Lehigh University, Bethlehem, PA, USA

Science has a long history of serving society, from the harnessing of fire, to development of tools and technology for commerce and war, and now to addressing global issues. In long-term symbiosis, science provided social systems with the knowledge required for development and security, while society ensured that the scientific community had the resources and support needed to function most effectively. In modern times, 20th century scientists were viewed like "industrialists," working to exploit natural resources for growing economies in an "open world" in which consumption and disposal were accommodated by the physical, chemical, and biological processes throughout the global ecosystem. In the 21st century, however, society is increasingly treating scientists as "physicians," turning to the scientific community to find ways to repair damage caused by overexploitation of the very resources that enabled rapid economic development, and that are now in jeopardy. As societies begin to understand that their economies and long-term well-being depend on the rate at which the global and local environment provide a broad spectrum of good and services, and that this rate is rapidly declining due to overexploitation, science is in a position to provide the knowledge necessary to restore the rate of provision of these goods and services. In effect, we are "living off the interest" that the stock within the global ecosystem provides, but in recent decades, we have rapidly "eaten into the principal" thus reducing the "interest," just when we need to increase it due to the burgeoning human populations demand for energy, food, and material goods. Although the modern scientific community has been aware of this unsustainable situation, communication between science and society has fallen to all-time lows in many areas, rendering science and society askew in that they are operating toward different goals, and the gulf widens. As a result, political decisions are often made that exacerbate the reduction of ecosystem goods and services, while the scientific community is marginalized in its influence on the political process.

In 2000, at the turn of the century, the International Geosphere Biosphere Programme followed on the approach of the 19th century mathematician, David Gilbert, and challenged 21st century scientists with 23 difficult questions, the answers to which could provide the guidance needed to restore and sustain the rate of provision of environmental goods and services that would support future societies. Some of these questions pertain to the operation of the Earth system, while others are more strategic, relating to societal goals. One of the most difficult of these was the question "What kind of nature do societies want?" This kind of normative question is not subject to scientific analysis, but relies on an organized vision regarding the future of each societys relation with the natural environment and what it provides.

While society needs from science the answers to such questions and many others, science needs the support of society to make any progress at all toward answering them. As the gulf between the scientific and political communities widens, global environmental issues are often politicized and support is reduced for the very scientific community that could help ease the transition into a sustainable relation with the global ecosystem. For example, the U.N. Millennium Goals include the eradication of poverty, and the Post-2015 Agenda involves stabilization of global climate. Yet, research on climate change is being stifled in some key societies. Aggressive policies based on the best scientific insights available at this point will be necessary in order for these two U.N. goals not to be in direct conflict.

As scientific techniques, models and results become more complex, the distancing from mainstream society is exacerbated by numerous misconceptions and miscommunications. These include concepts such as truth, objectivity, uncertainty, and underlying motivations. Miscommunication is sometimes caused by drastically different vernacular in scientific and lay circles. Scientists have become notorious for speaking in terms that make sense strictly in a scientific context, but not in a social or political context, in vain attempts toward "turning them all into scientists." While we would like to think that the entire citizenry should become scientifically astute, this approach is clearly untenable. Yet, only an informed populace can appreciate and thus benefit from the role of science in decision-making. So a critical question becomes "How can we most effectively provide scientific results and understanding to the general population in the face of rampant misinformation promoted by those in whose short-term interest it is to prevent decision-making based on science?"

The way forward necessarily involves a scientific community that understands and works within the value system of the society that depends on it (and that it depends on). This requires "speaking their language" not only in words, but in context. As such, outreach and education efforts on the part of scientists need to be both re-oriented and intensified. While decisions regarding resource consumption and distribution, human population, and the logical basis for decision-making may appear obvious to scientists, understanding that the world-view of much of the population is quite different will enable the scientific community to more effectively provide the needed insights in the service of society.

Use of Surface-Dynamic Models for Identifying Environmental Indicators and Processes

JP Syvitski, Community Surface Dynamics Modeling System — CSDMS, University of Colorado, Boulder, CO, USA

The three pillars of 21st century environmental cyber-infrastructure are: 1) satellite observations, 2) field observations, and 3) model simulations. While our 20th century efforts using this combination are legion, we now recognize the effort to develop effective state-of-the-art operational workflows. Each of the three pillars, on their own, contains substantive bias and error. Field observations also tend to be expensive and seldom offer the same spatial coverage as satellite systems or numerical models. Satellite systems have both spatial and temporal restrictions, based on the nature of the orbit, data transfer limitations, and other environmental restrictions (e.g. cloud cover, atmospheric moisture). Model simulations offer great temporal and spatial resolution, but are labor-intensive, and affected by model simplicity, computational resources, and eff ciency of the code itself. However when combined, these cyber-infrastructure pillars offer greatly reduced bias and error. Three examples highlight the role of model simulations in 21st century environmental cyber-infrastructure.

The f rst example highlights the application of nested and coupled models used to assess the role of hurricanes on offshore infrastructure. The Gulf of Mexico is a mature offshore petroleum production area generating more than 1.7 mb of oil per day, through more than 3,500 oil platforms, connected by 28,000 miles of underwater pipes, all exposed to different types of structural damage associated with extreme oceanic and atmospheric events. About 5% of broken or damaged underwater pipes are by sudden and violent sediment f ows. Short-lived hurricanes can generate 10m waves during their passage and both liquefy and re-suspend seaf oor sediment, and thereby induce turbidity currents. The U.S. Bureau of Ocean Energy Management has overseen the development of a complex array of nested and coupled numerical models for determining the locations most likely impacted by turbidity currents, and the factors that precondition or trigger such f ows. The workf ow includes: 1) modeling the f ux of water and sediment from rivers into the Gulf, augmented by f eld data; 2) ingesting outer boundary conditions from more regional oceanographic models, and seabed sediment textures; 3) employing a high resolution (10 km) wave action model and 4) a lower resolution (1 km) ocean circulation model, to support 5) a wave-driven sediment-suspension model, and 6) a gravity f ow setup model to determine the location and duration of areas of potential turbidity current generation. A Navier-Stokes Reynolds Averaged version is then used to route the sediment f ows down canyons, providing estimates of bottom shear stress needed for ascertaining possible damage to offshore infrastructure.

The second example highlights how models are used to assess the importance of environmental processes and parameters. In coastal deltas, surface elevation change is complex, involving: crustal motion, climate and runoff, vegetation dynamics, sedimentation, sediment compaction, and sediment transport by waves, tides and currents. Few existing instruments can measure the impact of all of these processes, and none resolve elevation changes across all pertinent spatial and temporal scales. No numerical model fully captures these terrestrial and subaqueous dynamics, although recent versions of Delft3D capture many of the morphodynamic impacts. When applied to the Louisiana coast, both cold fronts and hurricanes are shown to cause erosion of the Mississippi delta. Although a single hurricane can move more sediment, cold fronts are more critical for delta evolution as they transport much more sediment away from the coast due to their higher frequency nature. Waves intensify sediment erosion, and aboveground vegetation reduces the amount of erosion. Models can capture the impact of plausible scenarios, such as how the order or frequency of weather events inf uences delta stability. Combined with observing systems, model applications offer guidance to stakeholders needing information on our disappearing deltas.

Measurements of river discharge and watershed runoff are essential to water resources management, eff cient hydropower generation, accurate f ood prediction and control, and improved understanding of the global water cycle. Our third example focuses on river f oods. Optical (near-infrared) and SAR satellite systems are great for mapping f ood inundation but cannot on their own detect cause. As the number of large and devastating f oods have increased over the last couple of decades, it remains important to ascribe a cause to these f oods, such as from the intensif cation of the hydrological cycle or changing weather patterns either due to climate change, or from infrastructure failure of levees, barrages and diversions. Orbital (advanced) microwave sensors can measure river discharge variation in a manner closely analogous to its measurement at ground stations. For international measurements, hydrological modeling provides the needed calibration of sensor data to discharge. Comparison with gauging station data commonly indicates a need of small positive bias removal for both the modeled discharge and the satellite-observed runoff, highlighting the importance of all three pillars of 21st century environmental cyber-infrastructure.

Essential Ocean Variables for Biogeochemistry, towards indicators and indices

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The Global Ocean Observing System (GOOS) is working towards def ning essential ocean variables, development of targets for the observing networks and def ning observing system metrics and the assessment of risk to the observing system. GOOS is essentially focusing the work around a framework known as FOO — Framework for Ocean Observing — an outcome of the OceanObs conference in 2009 that was driven by a strong will to work collectively among ocean observing groups. The FOO is organized around the concept of essential ocean variables (EOVs), rather than around observing platforms. GOOS aims at delivering an observing system that is f t for purpose and is driven by scientif c inquiry and societal issues. While the FOO balances research with the need for sustained observations, it def nes a system that is based on requirements, observations, and data and information. The concept of readiness level is important for the FOO and is based on assessment of feasibility, capacity and impact.

This talk will focus on the efforts of the biogeochemical panel of GOOS in formulating societal requirements and def ning EOVS for biogeochemistry, and point to a way toward def ning indicators and indices of the observing system and ocean “biogeochemistry state”, feeding back to the societal requirements that motivate the EOVs.

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