

## → GEO AND SCIENCE

**A report prepared by the European Space Agency in the framework of the GEO Science and Technology Committee in support of the GEO Task ST-09-01 “Catalyzing Research and Development (R&D) Resources for GEOSS”**

Edited by Jean-Louis Fellous  
and Jérôme Béquignon

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## Executive Summary

*“The vision for GEOSS is to realize a future wherein decisions and actions for the benefit of humankind are informed by coordinated, comprehensive and sustained Earth observations and information.”* A number of challenges are still to overcome before this vision, set forth in 2005 by the Group on Earth Observation, is realised. Approximately the mid-point of the 10-year GEOSS Implementation Plan this report provides a synthetic image of the landscape with respect to the scientific research challenges that need special efforts for this Global Earth Observation System of Systems to develop and deliver its benefits to society. The report also draws the attention of the research community to the specific benefits for science and research that will stem from a fully-fledged GEOSS. The document has been prepared by a group of renowned experts and scientists, through an initiative of the European Space Agency, as a voluntary contribution to the GEO Task ST-09-01 under the responsibility of the Science and Technology Committee. The report is offered for consideration by the national agencies involved in funding research for GEO and GEOSS, particularly through the International Group of Funding Agencies for global environmental change research (IGFA), with a view to help identify research priorities and “catalyse R&D resources for GEOSS”. It is also intended for distribution to research communities, with a view to encourage their increased involvement into GEO.

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## 1. Introduction and Context

The intergovernmental Group on Earth Observations (GEO) was formally initiated in 2005, with the adoption of an Implementation Plan aiming at establishing a comprehensive, coordinated and sustained Global Earth Observation System of Systems (GEOSS) by 2015. GEO is now reaching its mid-point, and though significant progress has been made since its inception, a number of issues are still pending, which need to be resolved in order for this ambitious goal to be achieved.

The International Group of Funding Agencies for global change research (IGFA) recently expressed concerns, relating primarily to “the integration of science issues into GEO reflections and the extent to which they are being taken into account in the GEO Work Plan”. IGFA further stated that “the projects that GEO undertakes are key to advancing the Work Plan and observations must support scientific activity under the Plan”, and requested more information in this regard from the GEO Science and Technology Committee (STC). In this context the European Space Agency, in its capacity of Participating Organization within GEO and a co-Lead of the GEO Task ST-09-01, has proposed, in close coordination with the STC, to review the current GEO Work Plan 2009-2011 (as updated after the GEO-6 Plenary held in Washington DC, USA, in November 2009) with respect to support to science activity and integration of IGOS themes, and to identify underlying critical research needs.

It is useful to recall the overall goal of IGOS “to produce comprehensive global, regional and national data and information to satisfy the environmental information needs of policy-makers, and so support scientific and operational environmental programmes”. Founded in 1998 IGOS adopted a process of themes (including Ocean, Global Carbon Cycle, Geo-hazards, Water Cycle, Atmospheric Chemistry, Coastal Observations, Land, Cryosphere) in which observations are made for selected fields of common interest among a group of partners. The IGOS Partnership was later transitioned into GEO. At their 15th Meeting on 28 May 2008 at UNESCO in Paris, the IGOS Partners declared their satisfaction with the Transition of the IGOS Themes into GEO. IGOS accomplishments were celebrated in a Symposium held on 19 November 2009 in Washington, DC, USA. It remains however to the GEO Communities of Practice which have inherited the IGOS-P mandates to build on these accomplishments over the next few years.

The present report results from a focused effort aimed at clarifying the mutual interaction between Earth science and the development of GEO. It is based on contributions of a number of esteemed scientists covering the various disciplines of relevance to GEO. It has been subject to careful review by a broader community of users and scientists. The report includes an outline of the scientific research needs that are considered critical for reaching GEO objectives (priority research areas, defined in broad terms for each SBA, are highlighted in grey boxes throughout the text in Section 3). It also reviews the scientific benefits that would stem from a fully-developed GEOSS in the various areas of interest. It is brought to the attention of IGFA members and national funding bodies with a view to help orientate research calls and resource allocations.

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<sup>1</sup> ST-09-01: Catalyzing Research and Development (R&D) Resources for GEOSS. The goal of this task is to “encourage” national governments and international organizations to address GEOSS Science and Technology needs in their R&D programmes”.

<sup>2</sup> See [www.igospartners.org/](http://www.igospartners.org/)

<sup>3</sup> [www.earthobservations.org/meetings/20091119\\_geo\\_igos\\_symposium\\_draft\\_programme.pdf](http://www.earthobservations.org/meetings/20091119_geo_igos_symposium_draft_programme.pdf)

## 2. GEO Societal Benefits Areas

GEO was initially launched in response to calls for action by the 2002 World Summit on Sustainable Development and by the G8 (Group of Eight) leading industrialized countries. These high-level meetings recognized that managing a globalised world sustainably required shared information; and that international collaboration on Earth observations was essential to achieve this. GEO is a voluntary partnership of governments and international organizations. It provides a framework within which these partners can develop new projects and coordinate their strategies and investments. As of September 2009, GEO's Members included 80 Governments and the European Commission. In addition, 58 intergovernmental, international, and regional organizations with a mandate in Earth observation or related issues have been recognized as Participating Organizations.

The main objective of GEO is to provide observation and information products in support of societal needs. GEOSS is intended to be active in a broad range of "Societal Benefit Areas" (SBAs). In its first decade, these were chosen to be:

- Reducing loss of life and property from natural and human-induced **Disasters**;
- Understanding environmental factors affecting human **Health** and well-being;
- Improving the management of **Energy** resources;
- Understanding, assessing, predicting, mitigating and adapting to **Climate** variability and change;
- Improving **Water** resource management through better understanding of the water cycle;
- Improving **Weather** information, forecasting and warning;
- Improving the management and protection of terrestrial, coastal and marine **Ecosystems**;
- Supporting sustainable **Agriculture** and combating desertification; and,
- Understanding, monitoring and conserving **Biodiversity**.

The overall structure of this report is essentially aligned, but a few exceptions, with GEO SBAs. The question of whether to follow this scheme or to adopt a more standard description of the expected contribution of GEOSS to scientific disciplines is a legitimate one. Of course such a presentation should have included some sort of mapping of disciplines to SBAs. From a scientific standpoint many of these SBAs overlap. For example one can argue that **Agriculture** is a specialised form of **Ecosystem**, and **Ecosystems** have of course a level of **Biodiversity**. Similarly **Climate**, **Water** and **Weather** are interleaved and all cross-cutting themes for the other SBAs. GEO is designed to *present the world as the users see it*, not as the scientists see it. The multiple links and overlaps within the Earth observation field are intrinsic to the interconnectedness of the global system and are a powerful reason for taking an integrated approach.

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<sup>4</sup> The authors recognise that scientific activities are also included in the cross-cutting work of the Architecture and Data Management domain, for example the so-called QA4EO (DA-09-01a – Quality Assessment for Earth observation) which relies on scientific investigations to assess quality through validation, or the development of global data sets which implies a range of scientific activities. This report does not cover these important aspects, in view of their more generic character and for the sake of simplicity.

### 3. Research Needs Associated with GEO SBA's

The role of GEOSS is to coordinate improved access to and use of Earth observations for societal benefit. All of the operational techniques and methods used currently in GEOSS were initiated in the research domain. In this sense GEOSS should be identifying improvements to the observations and methods that need to be undertaken in the research domain and partnering with the research agencies to ensure that the underpinning research for future observations and techniques is being undertaken.

Though global change science requires monitoring by definition, there has long been a tension between research and monitoring. In fact this tension has its source in the institutional gap whereby research agencies do not perceive monitoring as being their responsibility while operational agencies are driven by operational needs rather than science. Many scientists who work on both sides of this arbitrary distinction can see both points of view and the essential commonality of their endeavours. This tension can be made to be a synergistic source of creativity, rather than an impediment.

Research is, and always has been, based on observation. Observations, to be useful, must be scientifically sound and relevant. The connection is close and obvious when the researcher is also the observer. But this restricts research to those phenomena which are displayed over a relatively short period of time, within a local space, and do not in most cases require highly-specialised observation skills. Many phenomena important to both science and society fall outside this range. They can only be scientifically investigated by relying on the sustained, standardised observations of many people, some of whom cannot hope to see the outcome of their work. In many domains, the architecture of science has developed a research pillar, an observation pillar and an assessment pillar, all of which are mutually interdependent and somewhat overlapping. For example, in climate change, research is coordinated by the WCRP, assessment is performed under the auspices of the IPCC, and observation requirements are advocated by GCOS. Similarly in biodiversity the pillars are represented by DIVERSITAS, IPBES and GEO BON. The coordination of this structure is clearly of paramount importance. Its starting point must be mutual respect for the integrity of each sphere of authority.

Researchers are always bemoaning the shortage of quality, long term data, but are very reluctant to share the limited resources available to science to help fill this gap. Proposals that are seen as “just monitoring” get short shrift in the peer-review process, as do data-reporting papers seeking publication. Observation-oriented scientists feel unappreciated as a result. On the other hand, they often fail to see the research opportunities afforded by their own data, and can be slow to respond to the changing needs of those who use the observations. For instance, in the field of biodiversity, a similar tension exists between taxonomists and ecologists or conservation biologists. Reliable taxonomies are fundamental to biodiversity science, but the characteristics of a good taxonomist almost by definition disqualify him/her from a science-funding system that rewards innovation and quick products. To optimise the health of the entire scientific enterprise, the different domains really need to be treated separately, according to their own needs and merits. But this does create the possibility of divergence (ghetto-isation) in what really needs to be an integrated system. GEO offers a wonderful opportunity to avoid this trap.

Understandably, the process by which GEOSS has initially generated its short-term Work Plan was somewhat ad hoc. Partly this can be attributed to the newness of the enterprise, but other causes were (i) the reliance on voluntary, unfunded efforts (with some notable exceptions, e.g. in Europe) to achieve the objectives means relinquishing much of the control over priorities; (ii) the “political” nature of the GEO Plenary decision-making structures. This process has improved, as the Work Plan goes through an extensive update



cycle and is approved by Plenary annually. Every 3 years it goes through a major overhaul, based on GEO community feedback. But suboptimal as it is, GEOSS nevertheless has great relevance to research and its working groups are composed overwhelmingly of researchers; and the larger the involvement of the research community, the better for improving the Work Plan adequacy.

Each subsection hereunder includes a short account of the state-of-the art in the area and addresses the scientific research needs that are considered critical for reaching GEO objectives – and by the same token advancing our overall understanding of the Earth system and our predictive capacity of its evolution and its impact on society. Particular attention is given to the relevant GEO Tasks . Gaps in research and potential shortcomings are identified. Similarly critical infrastructure needs (space-based and non-space-based observing systems, computing facilities, etc.) are outlined.

Whenever applicable, the integration of the former “IGOS Themes” into GEO is assessed. The GEO Work Plan obviously cannot address all needs at once. Nevertheless, better integration of the IGOS themes into the GEO/GEOSS framework could be achieved by a comprehensive examination of the major recommendations of each IGOS theme, including a grouping and prioritization.

A specific Work Plan task in the GEO Work Plan to examine the major recommendations of each IGOS theme, perhaps led jointly by the Science and Technology Committee and the User Interface Committee, would be beneficial.

### 3.1 Disasters

*The GEO Work Plan 2009-2011 [1] includes four main Disasters Tasks, namely: DI-06-09 – Use of satellites for risk management; DI-09-01 – Systematic monitoring for Geo-Hazards risk assessment; DI-09-02 – Multi-Risk management and regional applications; and, DI-09-03 – Warning systems for Disasters, as well as a number of other cross-cutting and thematic tasks which have direct or indirect relationship with the Disasters SBA.*

Disaster management only recently became a discipline per se in social sciences. Due to the variety of physical phenomena giving rise to hazards, disaster management is interdisciplinary in nature and bears connections with other scientific disciplines such as geology, hydraulics, hydrogeology, pedology, ecology, meteorology, etc.

A first category of research needs is linked with the characterization of hazards, vulnerability and risk, and the identification and assessment of risks from natural hazards on global, regional and local scales.

This broad category includes acquisition and digital representations of the physical characteristics of the landscape of a given territory, at different scales. This includes inter alia, acquiring digital models of topography (slope and aspect, etc.), land use and land use changes, land cover classes, sealing, fuel (vegetation types), and the causes of fire (i.e. roads, assets and settlements), characteristics of fuel (moisture/dryness), characteristics or nature and stability of bedrocks. Updating or even creating regulatory mapping of hazardous areas is of critical importance and remote sensing data have a lot to contribute. Areas with limited or obsolete available information will benefit immensely from methodologies being developed in information rich areas.

A second category of research needs is related to the modelling of physical phenomena such as fire ignition and propagation, flood, landslide, detailed volcano eruption, rainfall/runoff relationship, etc.

<sup>5</sup> See [www.earthobservations.org/geoss\\_imp.shtml](http://www.earthobservations.org/geoss_imp.shtml)

What is at stake is the development of a capability to forecast hazardous events and their consequences, which necessarily implies an interdisciplinary effort. Such a capability requires the adequate assimilation of field observations into models with a view to provide effective decision support. This includes fire risk indices computed from a variety of parameters such as soil moisture, surface temperature, wind speed and direction, but it also needs understanding rainfall/runoff relationship in given catchments. Development, improvement and sustainability of systems, methods, tools and applications of modern technologies such as geographic information systems for recording, analyzing and providing hazard information for risk assessment, sectorial planning and other informed decision-making are also necessary. Many natural hazards processes depend on complex material properties and poorly understood dynamic processes. For example, volcanic eruptions, landslides, snow avalanches and earthquakes involve complex multi-phase mixtures (gas, solid, liquid), the properties of which are either poorly measured or understood. Laboratory measurements and experimental studies on natural and analogue materials will provide key information for accurate parameterizations of physical properties and dynamic processes within models, as well as model validation. While extreme rainfalls and water saturation of soils are often the cause of landslides, no actionable model and associated set of observables allow for an effective forecast of such phenomena. While several physical models of fault rupture or volcanic eruptions are available, a detailed understanding of the actual mechanism at a scale compatible with effective forecasts, reliable information on the physical parameters of a volcanic edifice, or a fault system in the case of earthquakes are still missing. Likewise, the mechanisms that trigger landslides exist but the conditions of soil water saturation are usually not available.

A third category of research needs relates to the development, improvement and sustainability of early warning systems, in particular as regards the scientific and technical infrastructures, systems and capabilities for research, observation, detection, forecasting and warning of geophysical, weather-, water- or climate-related hazards.

A considerable effort is being devoted to develop forecast methods with adequate time and geographic accuracy, parameters such as precipitation, wind speed, etc. that control extreme events such as flash floods, local storms or wave surges. While there is an active community in weather-related hazards, well-structured around hydro-meteorological institutes, there has been a need to set up a Community of Practice on Geo-hazards and Geology.

## 3.2 Health

*The GEO Work Plan 2009-2011 [1] includes three main Health Tasks, namely: HE-09-01 – Information systems for Health; HE-09-02 – Monitoring and prediction systems for Health; and, HE-09-03 – End to end projects for Health, as well as a number of other cross-cutting and thematic tasks which have direct or indirect relationship with the Health SBA.*

### 3.2.1 Information systems for Health

The main objective of this task is to help the World Health Organization (WHO) develop a global information system for health, named OpenHealth. Such a system aims at integrating and archiving all epidemiological data from WHO member states, at district, regional and national levels. Syntheses are then made possible by extracting information from the database.

To be efficient, such a system would require WHO member states be equipped with up-to-date epidemiological data collection facilities, avoiding paper charts and preferably using the Internet. Unfortunately the economic constraints encountered by developing countries are a limit to achieving this goal. For that reason the members of the recently-created Community of Practice (CoP) “Health and the Environment” work collectively at promoting:

- Open source software development;
- Epidemiological data collecting system compatible at district, regional and national levels; and,
- Demonstration projects allowing equipping health specialists with Internet facilities for epidemiological data collection.

Funding such infrastructure projects is possible through international or national funding bodies but need a strong involvement of the Ministry of Health in developing countries.

### 3.2.2 Monitoring and prediction systems for Health

According to the GEOSS 10-Year Implementation Plan [2], “*Health issues with Earth observation needs include: airborne, marine, and water pollution; stratospheric ozone depletion; persistent organic pollutants; nutrition; and monitoring weather-related disease vectors*”. Many space agencies and environmental research agencies are involved in the above-mentioned GEO Tasks and have developed tools for mapping and modelling, using their respective own data sets and satellite imagery.

For that reason the CoP “Health and the Environment” co-led by India (represented by the ICMR), France (represented by CNES, the French space agency) and WHO aims at promoting common approaches and collaborative projects. In order to ensure that all these developments and flourishing initiatives become sustainable, the members of the CoP “Health and the Environment” have proposed a certain number of rules and good practices, the first of which being the request that any development has to be user-driven and should not promote a “techno-push” approach (such as placing satellite data in the first place).

For these reasons, it is recommended that forthcoming research projects integrate multidisciplinary aspects and follow a three-step approach:

- Understanding mechanisms at stake: Monitoring and assembling multidisciplinary in situ data sets to extract and identify the physical and biological mechanisms at stake;
- Pertinent use of remote sensors: Remote-sensing monitoring of environment, linking epidemics with ‘confounding factors’ such as rainfall, vegetation, hydrology and population dynamics;
- Contribution to early-warning systems (EWS): Use of bio-mathematical models for epidemic dynamics integrating remote sensing inputs, vector aggressiveness and associated risks in order to contribute to EWS.

Following that approach, CNES and its partners have applied this concept (developed in 2008 into a new patent on epidemiology) to several infectious diseases all over the world: (i) urban and rural malaria over the African continent (ii) dengue fever in Argentina (iii) vibrio diseases and cholera in the Mediterranean (iv) Rift Valley Fever in Senegal.

Similarly NOAA and its partners have developed risk maps for malaria for Africa and India; GISTDA has developed malaria risk maps in Thailand. But the same approach could also be deployed for air- and water-borne diseases.

New research is needed: in situ measurement campaigns are crucial to understanding the ecology and biology of any particular problem, but also to

validate space-based products for health. It is very difficult to obtain funding for this critical work, and when funding exists, data sets are jealously kept by research teams, and rarely made available to the GEO community.

*In situ* measurement campaigns of entomological, epidemiological, environmental, climate, microbiological data for GEO should be encouraged and funded. And data funded in support of GEO should be delivered to the GEO community on the GEO Portal.

Supporting *in situ* measurement will definitely give an impulse to GEO Health related activities.

### 3.2.2 Monitoring and prediction systems for Health

Within the objectives of GEOSS global end-to-end projects for health have to be encouraged. Current projects include applications to meningitis, malaria, and Lyme diseases, in order to advance the application of observation, monitoring, and forecasting systems to health decision-making processes.

Some of the biggest challenges and cornerstones for these projects to become sustainable are:

- The involvement of the health users;
- The understanding of their needs and funding capacities;
- The availability of infrastructures;
- The possibility to access data (space-based imagery and *in situ* measurements) and models; and,
- The cost of the solution.

Moreover the CoP “Health and the Environment” aims at federating individual initiatives into global ones in order to favour common practices and when possible standards.

Downscaling and upscaling between various tailored remote-sensing products made for end users in such end-to-end projects for health remain a research issue. Projects aiming at merging very high resolution with high and low resolution satellite imagery should be encouraged.

## 3.3 Energy

*The GEO Work Plan 2009-2011 [1] includes three Energy Tasks, namely, EN-07-01 – Management of Energy Sources; EN-07-02 – Energy Environmental Impact Monitoring; and, EN-07-03 – Energy Policy Planning, and a number of other cross-cutting and thematic tasks which have direct or indirect relationship with the Energy SBA.*

One of the biggest challenges faced by the energy sector today is to extract a maximum of energy – from fossil and renewable energy resources – while minimizing cost and impact on the environment. Meeting this challenge requires accurate and timely information on a variety of environmental parameters (e.g. wind speed, surface solar irradiance, snow extent and thickness, geological features) as well as on the operating conditions of energy exploitation activities (e.g. weather conditions, topography, vegetation cover, met-ocean stress on offshore platforms) and the environmental impact of the use of energy (CO<sub>2</sub> equivalent, greenhouse gases, etc.) in order to aid decision-making.

Earth Observation (EO) from space offers an effective approach to quantify some of the parameters, as satellites are able to remotely monitor our environment at the global scale (even in the most remote places) in a consistent manner (in space and time). These unique characteristics of wide-area EO

data, complementing – but not replacing – traditional point-based in situ data, make them very useful to support energy operations ranging from exploration, extraction, operations, up to the transport and environmental impacts of energy.

However, in a similar way as the process of refining crude oil to make it useful, raw EO data (e.g. mainly radiances or backscatter) need to be turned into information tailored to the needs of decision-makers to be deemed valuable. This (cross-cutting) data-to-information conversion process is not an easy task and poses fantastic challenges to the research community in order to make full use of the various EO data streams. Some EO-based applications supporting the energy sector and their related scientific challenges are discussed hereunder.

### **3.3.1 Quantifying met-ocean conditions to support optimal siting of offshore wind platforms**

Wind energy is entering a golden age with the fastest growth across the whole renewable energy industry. The financial success of wind farms is strongly bound to the wind resources available over the plant life-time (hence the revenues) but also to other factors affecting the initial investment such as the impact on environment, access to turbines for maintenance and connection to the grid network for distribution (hence the cost). When looking to offshore wind farms, quantifying these factors and the met-ocean conditions is critical to perform technical and financial feasibility studies of prospective sites but also to secure long-term investment.

The traditional way to assess the potential energy yield of a prospective wind farm is by using data from a meteorological mast, which is very expensive for offshore wind farms, in terms of installation and maintenance. Although this approach is accurate, it can only provide point-measurement data for a short period of time (typically one year), while the wind field is generally highly variable in space and time due to local coastal effects. Using local data and their representativeness can therefore be an issue to effectively assess the “bankability” of prospective farms. In contrast satellite measurements of ocean winds provide a more comprehensive and spatially resolved view of the wind climatology and the entire probability distribution.

Moreover, coastal wind farms are often in shallow water with bottom visibility. It means high resolution satellites and airborne remote sensing can be used to study bottom substrates and benthic habitats. Collecting this data over large areas with fine enough spatial resolution by means of diving is unrealistic. It means that remote sensing can be used to plan optimal (from both an ecological and an economical standpoint) locations of wind farms and each individual structure in it.

The monitoring from space of met-ocean conditions (and their associated climate statistics), in particular in the coastal ocean where most of the action takes place, cannot yet meet the accuracy and space-time sampling needed for energy applications, and therefore requires extensive research, including validation and the development of the new generation of retrieval algorithms and multi-sensor fusion techniques.

### **3.3.2 Assessing potential run-off to support hydropower activities**

The energy of moving water has been harnessed for millennia for a variety of purposes, ranging from powering mills to produce flour from grain or pumping water into irrigation networks. Today, hydropower is mainly used to generate electricity, supplying up to 20 percent of the global production of the world electricity, mainly through large dams. One key advantage of hydropower, over other types of “intermittent” renewable energy, is its ability to store energy and therefore to manage peak load demand. However, one drawback of large

dam infrastructures is often their significant impact on the environment. Water reservoirs are significant source of methane. It has been shown that in the tropics 90% of methane emissions come from artificial reservoirs, a large fraction of which are built for power generation.

In mountainous areas, a large portion of the “potentially available water” is stored in the seasonal snow pack and provides “fuel” to the hydropower reservoir during the snow melt period. Precise information on the snow reserves, amount of precipitation and accurate predictions of the onset of snowmelt are therefore required to optimize hydropower production.

Satellite data can assist in this process by providing timely measurements of key hydrological parameters and terrain conditions affecting the river run-off. The wide-area mapping of EO data is particularly useful in this regard, as it complements conventional point measurements of snow, which are usually sparse or even completely missing in remote mountain areas.

Much research remains to be done in order to accurately estimate from space the “hydrological” parameters – such as precipitation, snow water equivalent, snow cover, soil moisture and land temperature – critically needed to initialize, validate and constrain run-off models, as well as to assess the environmental impacts of hydropower.

### 3.3.3 Quantifying solar radiation to optimize operations of solar energy plants

Meteorological satellites can provide global maps of irradiance up to 1 km resolution several times per hour. By combining these irradiance maps with other EO products, such as Digital Elevation Model and cloud cover maps, it is possible to estimate the optimal solar energy yield expected from a solar energy power plant. The ability to go back in time in the archive of Meteosat data – spanning several decades – provides the long-term time series and statistics of direct/diffuse solar irradiance together with cloud conditions necessary to quantify solar resources. EO further allows the quantification of atmospheric turbidity based on aerosols and water vapour, which reduces surface solar irradiance.

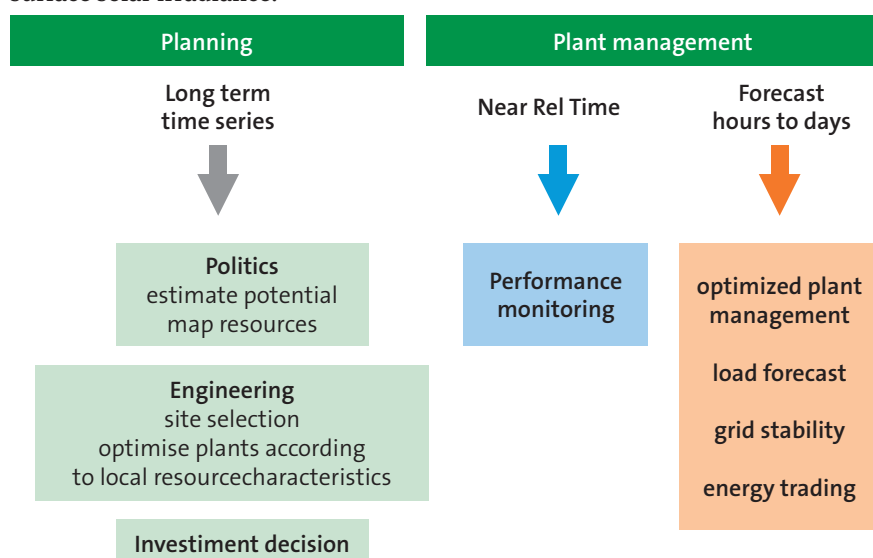


Fig. 1 Potential application fields in the energy sector for long-term monitoring, nowcasting and forecasting approaches in EO.

Although very promising, space-borne remote sensing of ground-based solar radiation (e.g. direct/diffuse irradiance) requires better understanding of radiative transfer modelling, and in particular with regard to the effects of clouds and aerosols.

An EO-based information service for solar resource monitoring (Figure 1) can help solar energy managers to site a system in a suitable location, to adapt its engineering parameters to local climatic conditions, to automatically assess performances of solar energy power plants (i.e. by comparing over a month the actual solar energy yield with the average one expected from satellite data), to rapidly detect faults, and overall therefore reduce costs and improve revenues.

### 3.3.4 Characterizing the underground field to optimize seismic surveys

Seismic surveying is by far the most important tool used by the oil and gas industry to build a complete picture of the underground geology. Today, the most sophisticated technique for accurate seismic land-based surveys is the so-called “vibroseis” method, which works rather like an underground radar, whereby sound waves are excited at surface by large vibrator trucks and then recorded by a large array of surface sensors called geophones. By studying the reflection of elastic waves on the various rock layers, geologists are able to build a fully three-dimensional image of the reservoir, with a high level of details (e.g. fractures) enabling well engineers to extract as much hydrocarbon as possible. Accuracy however comes with a significant cost, as a survey of a 500-square-kilometre area can require more than 400 people with up to 50 small and 15 large vehicles working with up to 600,000 geophones, and carrying out 600 seismic “shots” daily. One of the issues of seismic surveyors is to maximize the signal-to-noise ratio by ensuring a good coupling between the emitters and receivers. To do so, it is advised not to place trucks above very hard rock (e.g. basalt acts as a massive reflector) and geophones above rocks creating acoustic distortion of the signal.

Space-based observations can assist this process by characterizing, at small cost and prior to the survey, the regions’ topography, terrain conditions and lithological characteristics (e.g. presence of massive reflector such as basalt). This information can then be used to assess areas that will produce the best seismic surveys and place optimally emitters and receivers.

Much research is still needed to fully exploit the combined capability of different EO sensors (e.g. optical and radar) to better characterize the terrain conditions (e.g. roughness, land cover), and topography at a level of details and accuracy needed by surveyors and energy planners.

### 3.3.5 Monitoring land motion to support drilling and carbon capture activities

Monitoring of surface deformation is of critical importance in oil drilling /pumping activities (e.g. subsidence issue when oil is extracted from underground reservoir) and “Carbon Capture and Storage” (CCS) activities (uplift issue when carbon dioxide is injected into underground reservoirs). Traditionally, engineers rely on GPS surveys to monitor ground deformation. Although very accurate, this method is however resource intensive (e.g. data processing) and can only provide an incomplete point-based picture of the subsidence issue. Today, minute motions of the Earth’s land surface can be monitored from space within sub-centimetre accuracy thanks to a powerful surveying technology called “Interferometric Synthetic Aperture Radar” images (InSAR) based on imaging radar data from missions such as ERS, ENVISAT or RADARSAT. This new cost-effective technology provides a two-

More generally, there is a critical need to foster the development of physically-based retrieval algorithms, the improvement of multiple sensor merging techniques, the validation, traceability and error characterization of EO products, and their integration/assimilation within numerical models.

dimensional overview of subsidence, which complements local level ground measurements and helps engineers to quickly identify problem areas. However, although very powerful, this method suffers from inherent limitations related to the effects of the atmosphere or changing terrain (e.g. vegetation cover).

Fundamental (e.g. process-oriented) and applied (e.g. user-oriented) research are of paramount importance to improve the capability of interferometric methods (e.g. permanent scatterers) and better understand their limitations.

### 3.4 Climate<sup>6</sup>

*The GEO Work Plan 2009-2011 [1] includes four Climate Tasks, namely, CL-06-01 – A Climate Record for Assessing Variability and Change; CL-09-01 – Environmental Information for Decision-making, Risk Management and Adaptation; CL-09-02 – Accelerating the Implementation of the Global Climate Observing System; and, CL-09-03 – Global Carbon Observation and Analysis System, and a number of other cross-cutting and thematic tasks which have direct or indirect relationship with the Climate SBA.*

It is helpful to divide climate observations into three categories: (i) sustained observations – acquired on a semi-permanent basis; (ii) process study observations – required to augment the network of sustained observations for understanding key processes; and, (iii) enhanced monitoring – observations that are needed to fill the gap between the “sustained” and “process” categories.

In addition to the longer-term data for climate monitoring and analysis of time-dependent variations, there is a need to collect, analyze and archive high spatial and temporal resolution data of physical variables and chemical constituents using in situ as well as remote-sensing methods.

The coordinated collection, analysis and reanalysis of climate observations are required to describe the structure and variability of the climate system. This will allow the generation of descriptions of states of the coupled atmosphere-ocean-land climate system that are consistent with both the observations of all variables and the physical framework provided by models, both for the numerical prediction of climate and for documenting the climate record.

More complete exploitation of observations and improvement of models necessitate a major activity in climate/Earth system data assimilation.

This is already occurring in some operational centres as an extension of numerical weather prediction procedures. It requires the best climate/Earth system models and is an excellent test of them. Maximum possible value of observations is obtained by combining them with other observations in the context of the model. The resulting products are essential for providing best estimates of the current state of the climate and for many uses in the context of the development, use and evaluation of climate models. Independent observational data sets and analyses are also required to make an independent check of both models and analyses.

From the onset GCOS has been recognised as the climate component of the GEOSS. Observations should adhere to the Global Climate Observing System (GCOS) monitoring principles [3], thereby ensuring that they are useful for multiple purposes, including climate change. A commitment is required for the progressive, coordinated, ongoing analyses and periodic reanalyses of observations, which are necessary to incorporate lessons from new measurements and research. Commitment is also required for the stewardship, archival and access of data, as well as the support to enable institutions to

<sup>6</sup> This section draws on material from a report on Observations presented by K. Trenberth and S. Gille at the 31st meeting of the Joint Scientific Committee of the World Climate Research Programme, Antalya, Turkey, 15-19 February, 2010.



do these tasks. A balance is needed between new observations and the need to achieve more effective exploitation of current and planned observations (especially from satellites), the latter being achieved through increased international cooperation on developing integrated analyses and products. The transition from research to operational systems is also an important practical issue. A major concern is the development and improvement of Fundamental Climate Data Records (FCDRs) which can be used for studies and assessments of climate variability and change, such as for IPCC. The European Space Agency's Climate Change Initiative addressing as a first step eleven satellite-based ECVs provides a good model in this respect.

Particular concerns for which some activities are underway and should be sustained include:

- Continuity and homogeneity of observations, especially from space;
- The need for reprocessing of records in a coordinated way and with agreement on algorithms, and comprehensive validation, evaluation and assessment of results; and,
- The need for reanalysis to produce global gridded fields.

Promotion of reanalysis has been successful, leading to a problem of proliferation of reanalyses without the ability to adequately vet them. Reanalyses have been or are directed at producing the best series of analyses given the observations. None, so far, have been directed at fully addressing spurious effects of the changing observing system on the record. Dataset development and stewardship, archival and data management of records are needed in ways to facilitate reanalysis and access.

Consideration needs to be given to identifying gaps and deficiencies in existing observing systems, encouraging reprocessing and reanalysis of past data, and addressing other shortcomings which may have resulted in reduced skill of existing prediction schemes.

Consideration needs to be given to identifying gaps and deficiencies in existing observing systems, encouraging reprocessing and reanalysis of past data, and addressing other shortcomings which may have resulted in reduced skill of existing prediction schemes.

New observational data, particularly those from the new generation of satellites, will be exploited to the maximum possible extent. A particular aim is to determine what can be predicted and how it can be done. Hence, the climate research community has to position itself to help argue for the climate observational system that will be required in future for both assessments of the climate system and for prediction. There is a need to continue to provide a coordinated input into the international process of defining the in situ and space observing systems for the next decade required for climate studies and in particular to address the aims and objectives of climate research.

Special efforts will be required to obtain, analyze and assimilate data from the new generation of environmental satellites.

Because global warming is “unequivocal” [4], and some warming is guaranteed, adaptation to climate change is essential. This requires information to assess vulnerability, devise coping strategies, determine possible impacts, and plan for future changes.

In accordance to the above the World Climate Research Programme (WCRP) is devising the following research strategy [5] that should be actively supported:

- Advocate improved observations and analysis suitable for climate (satisfying the GCOS Climate Monitoring Principles that are designed to ensure continuity of record). This especially includes those from space.
- Data set development: evaluating observations and promoting their reprocessing and reanalysis into global fields. Develop new products and datasets. Develop analytical and diagnostic techniques to process observations and model data. Develop new products and datasets, often high-level derived products, for use in understanding and analyzing climate variability and change, and for evaluating models.
- Continue to carry out studies on mechanisms and modes of variability that have contributed to observed climate anomalies. Further develop capabilities that contribute to an operational attribution activity by pioneering studies and numerical experimentation that might be used in near real time to allow reliable statements to be made not only about what the state of the climate is, but also why it is the way it is and the mechanisms involved. Studies involve the atmosphere and the fully coupled system.
- Promote improved data assimilation and analysis. Improve initializing of coupled models for prediction. Promote use of assimilation and analysis products and corresponding evaluation of their utility for different applications.
- Provide advice on best datasets for various purposes (climatologies and time series) and their merits and limitations. Error bars are greatly needed. High priority needs are to have assessments of datasets for use in evaluating climate models, and specifically those used in the AR5 IPCC report that will participate in the CMIP5 activity.
- Help improve and promote sound data stewardship, including data archiving, management, and access. This includes making sure that climate-related data variables are reaching data archives, and that standards are set for archiving new types of data. Help make data accessible and available e.g. through the internet. Promote shared efforts for data quality control.

## 3.5 Water

*The GEO Work Plan 2009-2011 [1] includes three Water Tasks, namely, WA-06-02 – Droughts, floods and water resource management; WA-06-07 – Capacity building for water resource management; and, WA-08-01 – Integrated products for water resource management and research, as well as a number of other cross-cutting and thematic tasks which have direct or indirect relationship with the Water SBA. The Work Plan contains one task specific to the cryosphere: “Legacy of the International Polar Year 2007-08”, AR-09-03b. Another subtask, “Accelerating the Implementation of the Global Climate Observing System” (CL-09-02), includes the Global Cryosphere Watch. A few other tasks address snow and ice issues at least peripherally (e.g. CL-06-01, EC-09-01).*

As it appears from the above paragraph the current Work Plan structure does not deal properly with solid water, i.e. ice. This section puts some emphasis on research issues related to the cryosphere with a view to help reassess its place in future versions of the GEO Work Plan.

### 3.5.1 Water

Water comprises the most basic and critical component of all aspects of human life and is an indispensable component of the global life support system. On the whole, the water environment is characterized by the hydrological cycle,

including floods and droughts. The widespread scarcity, gradual destruction and aggravated pollution of water resources in many world regions have triggered a range of water crises. The 4th Assessment Report of the IPCC projected more frequent heavy precipitation events, an increase in the area affected by drought, and more intense tropical cyclones (typhoons and hurricanes) associated with global warming [4]. To make sound decisions in water resources policy under conditions of climate change and an increasing population, one should address challenges such as the assessment of changes in hazards and disaster risk and the planning and management of adaptation measures.

A high degree of uncertainty still exists in the description and prediction of the water cycle under the current and future climates. One of the reasons for the uncertainty is the imperfect understanding of physical, chemical and biological processes. Even though tremendous efforts have been made to understand each process, interactions among the processes have not been well addressed, e.g. the monsoon circulations as the result of atmosphere-ocean-land surface interactions, the spatial and temporal variability of land surface moisture controlled by atmospheric forcing and vegetation, and the water cycle modification by natural- and human-induced aerosols.

Promoting interdisciplinary cooperative research in hydrology is strongly recommended.

It is recognised that sharing data and information among different disciplines is difficult because they have specialised and segmented as the contemporary science and technology have developed. Though this is certainly true in many domains it is of particular relevance to the water SBA.

There is a need to facilitate knowledge sharing among different disciplines by arranging interoperability of Earth environment data, and constructing data infrastructure where the data and information can be exchanged smoothly among different disciplines. Though this is certainly true in many domains it is of particular relevance to the water SBA.

For improving data interoperability, it is important to develop a system for identifying the relationship between data by using an ontology of technical terms and ideas, and geography so as to activate interdisciplinary water cycle sciences. In addition, the lack of computational resources causes critical problems especially for climate prediction, which requires as long an integration period as 100 years. Furthermore the limitation of the spatial resolution of models model is such that they cannot adequately resolve small-scale features such as cumuloform clouds or properly represent detailed topography in climate projections. To address these problems, each model adopts its own parameterization schemes and simplification procedures. Large discrepancies among models are thus generated, especially in the projection of rainfall. There are still large biases among models, especially on regional and river-basin scales, while the IPCC AR4 shows unified increases in the frequency of heavy rainfall events and drought area on a global scale.

The multi-model analysis is considered as an effective approach for quantifying and removing uncertainty by combining the global Earth observation data and re-analysis products, which cover the global to local scale water cycle.

Huge volumes of data, from several hundreds of terabytes to several petabytes, and diversity of climate projection and Earth observations have to be handled throughout these research activities.

An infrastructure for hydrological data integration and analysis that includes the supporting functions of life cycle data management, data search, information exploration, scientific analysis, and partial data downloading, should be developed.

With regard to inland waters, it should be noted that the models used by the IPCC completely ignore lakes and inland waters, which are dealt with as inert pipes transporting carbon from land to oceans. It has been shown that inland waters actually play a significant role in the global carbon cycle (comparable to oceans). The true role of lakes in the global carbon cycle could be determined by means of remote sensing in combination with in situ observations.

There is a strong need for GEO to bring the lake, river and coastal communities working on carbon cycle issues together with other carbon cycle scientists.

Finally one should note that the current GEO Work Plan suffers from a few significant gaps. First of all, most of the current water Tasks are water quantity-related and there is just one water quality-related Task.

Quantity of water is obviously globally a more important issue than quality, but drinking water quality, health related issues (diseases, harmful algal blooms, increasing dissolved organic carbon, etc.) and global carbon cycle problems deserve more attention.

Another problem is the gap between in situ and remote sensing in water related tasks. Most of the in situ component is 'land-related' (water quantity, hydrology, etc.) whereas most of the remote sensing community works on oceans. Many satellite products (at least, ocean colour ones) fail pretty badly in inland and coastal waters that are much more complex environments than the open ocean. Thus, there is strong need to get the remote sensing community working on coastal and inland water issues.

There are currently several inland and coastal remote sensing groups around the world but they are much more scattered than the "ocean" community and GEO can play here a significant role in bringing these groups and the remote sensing community together with the "land" in situ community.

### 3.5.2 Ice

The cryosphere collectively describes elements of the Earth system containing water in its frozen state. It includes sea ice, lake and river ice, snow cover, solid precipitation, glaciers, ice caps, ice sheets, permafrost, and seasonally frozen ground. The presence of frozen water in the atmosphere, on land, and on the ocean surface affects energy, moisture, gas and particle fluxes, clouds, precipitation, hydrological conditions, and atmospheric and oceanic circulation. The cryosphere exists at all latitudes and in about one hundred countries. Information on the cryosphere can contribute to all societal benefit areas of GEOSS. Snowmelt and glacier run-off are major sources of hydropower and in many areas the only sources of water for sustaining life and agriculture. Several natural hazards are directly related to the cryosphere including avalanches, icebergs, and catastrophic flooding from glacial lakes. The cryosphere affects all modes of transportation even at the local level where seasonal melt and refreezing can damage roads. Other sectors such as wildlife, recreation, and tourism are significantly affected by short-term and long-term changes in snow and ice conditions.

The IGOS Cryosphere Theme Report [6] assessed our current capabilities for obtaining priority snow and ice observations associated with weather/

climate and societal applications, specific observational requirements, and observational gaps. A comprehensive list of recommendations was also given. The recommendations are currently being reviewed and updated for the Arctic Council's "Snow, Water, Ice, and Permafrost of the Arctic" (SWIPA) assessment of the Arctic cryosphere, to be published in 2011.

With the transition of the IGOS themes to the GEO/GEOSS framework, it was hoped that many of the IGOS Cryosphere Theme recommendations would be incorporated into the GEO Work Plan. However, the observational needs detailed in the IGOS Cryosphere Theme and SWIPA reports are not being addressed comprehensively by GEOSS.

There are many gaps in the cryosphere observing system that are not addressed in the Work Plan. Of course, the tasks and subtasks in the GEO Work Plan are, by necessity, high level activities. For example, the goal of the IPY legacy subtask is to "...enhance the production and utilization of Earth observations in the realm of cryosphere." Presumably these "catch-all" tasks are meant to address very specific gaps in the observing system, as detailed in the IGOS, GCOS, and other reports. It is not clear, however, if this is actually occurring.

A few of the critical needs from the IGOS Cryosphere Theme that do not appear to be part of the Work Plan are:

- Basin-scale sea ice thickness measurements need to be further developed. Snow depth on ice is a major uncertainty in deriving ice thickness.
- Aircraft and satellite implementations of advanced ice sheet sounding synthetic aperture radars should be explored. The time series of space-borne gravity observations for monitoring changes in ice sheet mass and the contribution of ice sheet mass loss to sea level rise must be continued.
- Although snow water equivalent (SWE) is critically important, SWE observations are very sparse and are totally absent in many regions. Priority should be given to research and development of algorithms and new sensors to measure SWE.
- The glacier topography database is fragmentary and/or of poor quality. Space-based data are needed to improve it.
- An international network should be created to monitor seasonally frozen ground in non-permafrost regions. Soil temperature and frost depth measurements should be recommended as standard parameters to all WMO (World Meteorological Organization) and national cold regions meteorological stations.
- Precipitation gauge networks in the cold regions need to be sustained and enhanced. A bias analysis of historical precipitation gauge data at regional to global scale needs to be undertaken. The use of wind shields and the direct measurement of winds at emerging auto gauge sites/networks need to be expanded.
- Surface-based observations were once the most important source of information for lake- and river-ice conditions. The declining state of the surface-based networks since the mid 1980s has led to serious geographical and temporal gaps for several lake and river ice parameters (see Figure 2). Existing lake and river ice sites need to be reactivated and new observation sites added.

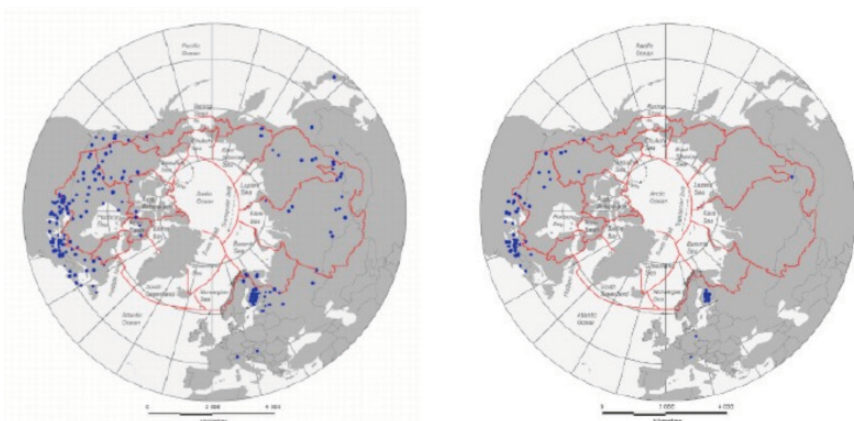


Fig. 2 Lake ice observations in 1970 (left) and 1995 (right).

A WMO Global Cryosphere Watch (GCW) would include observation, monitoring, assessment, product development, prediction, and related research. It is currently in the feasibility study phase, to be considered by the WMO Congress for development as a full-fledged program in May 2011. One of GCW's main goals is to implement recommendations of the IGOS Cryosphere Theme.

GEOSS could also be a mechanism to aid in the development of the WMO's Global Cryosphere Watch.

### 3.6 Weather

*The GEO Work Plan 2009-2011 [1] includes two Weather Tasks, namely, WE-06-03 – TIGGE and the Development of a Global Interactive Forecast System (GIFS) for Weather; and, WE-09-01 – Capacity Building for High-Impact Weather Prediction, and a number of other cross-cutting and thematic tasks (notably the Task CL-09-01a – Towards Enhanced Climate, Weather, Water and Environmental Prediction), which have direct or indirect relationship with the Weather SBA.*

Strengthening the ability worldwide to deliver new and improved climate, weather, water and environmental services requires developing dedicated research activities (CL-09-01a). These research needs, which necessitate a cooperative effort between the meteorological, climate and environment communities, can benefit from recent advances in observing technologies, field and laboratory process studies, data-assimilation techniques, and coupled numerical models of weather and climate prediction aided by high-performance computing advances.

The priority research topics include:

- Seamless weather/climate prediction including Ensemble Prediction Systems (EPSs);
- The multi-scale organization of tropical convection and its two-way interaction with the global circulation;
- Data assimilation for coupled models as a prediction and validation tool for weather and climate research; and,
- Information to assess the risks/benefits of climate/weather predictions on society and the global economy.

The World Meteorological Organization (WMO) provides the most appropriate framework to coordinate enhanced predictions through the development and implementation of “An Enhanced Climate, Weather, Water and Environmental Prediction strategy”. Such a strategy would seek to accelerate prediction research, assessments and their links to service delivery during the next decade. A Research Task Team set up by the WMO Executive Council has

recently released a report on the research aspects of an enhanced prediction framework including effective mechanisms for achieving an overall process where observations, data and analysis, research, modelling, assessment and prediction, services and capacity building will be the key components.

Current research focuses on organised tropical convection through the Year of Tropical Convection (YOTC) initiative . The very limited ability to simulate multi-scale organised convection is a fundamental barrier to improving weather and climate prediction. This effort is intended to exploit the vast amounts of existing and emerging observations and computational resources in conjunction with the development of new, high-resolution modelling frameworks, with the objective of advancing the characterization, diagnosis, modelling and prediction of multi-scale convective/dynamic interactions and processes, including the two-way interaction between tropical and extra-tropical weather/climate. It seeks to leverage the most benefit from recent investments in Earth Science and observations infrastructure.

Other specific research activities need to be initiated in the next few years including sub-seasonal to seasonal prediction as a joint effort between the weather and climate communities.

TIGGE (WE-06-03) is a global operational multi-model ensemble prediction system incorporating easily accessible databases. These international databases contain ensemble numerical weather prediction forecasts from 10 global weather forecast providers to advance scientific research related to improving high-impact weather forecasting. The shared data are made available for research purposes (with a time delay) at the three volunteer archive centres (CMA, ECMWF and NCAR) via site specific web interfaces (see <http://www.wmo.int/pages/prog/arep/thorpex/>).

Some important research needs critical to the successful implementation of TIGGE-GIFS include:

- The statistical bias correction of ensemble data;
- The combination of information from multiple sources/ensembles;
- The choice of products, and the algorithms to generate those products (this will involve strong collaboration with users through the WMO Severe Weather Forecast Demonstration Projects, SWFDPs and through Societal and Economic Research and Applications (SERA) type research);
- The web interface development for interactive TIGGE data and GIFS product access by users; and,
- The development of protocols for shared development of software, e.g. how remote groups can productively contribute to shared software and how this software can be used by multiple centres, etc.

The main research goal of THORPEX Africa (WE-09-01b) is to improve our understanding of high-impact weather events, assess their predictability and improve the ability to predict these events, particularly their timing, intensity and track. The high-impact weather events that are the focus in this task include: heavy rainfall and floods due to severe storms; tropical cyclones; severe extra tropical events; dry/wet spells; sand and dust episodes; severe winds due to tropical cyclones, severe storms, cyclogenesis; early or late onset and withdrawal of the seasonal rainfall; and, extreme temperatures.

<sup>7</sup> Available from [http://www.wmo.int/pages/about/sec/rescrosscut/documents/WMO\\_TD\\_1496\\_ECRTT.pdf](http://www.wmo.int/pages/about/sec/rescrosscut/documents/WMO_TD_1496_ECRTT.pdf)

<sup>8</sup> The YOTC Science and Implementation Plans may be downloaded from <http://www.ucar.edu/yotc>.

Some important research needs related to THORPEX-Africa include:

- The development of a High Impact Weather Information system for Africa;
- The improvement of the predictive skill of high-impact weather events in Africa;
- An enhancement of the use of non-conventional observing technologies;
- The design of an optimum observing network for Africa; and,
- The development of a seamless forecasting system for Africa.

### 3.7 Ecosystems

*The GEO Work Plan 2009-2011 [1] includes two specific tasks on ecosystems, namely EC-09-01 – GEO EcoNet, and EC-09-02 – Ecosystem Vulnerability to Global Change. Ecosystems are obvious components of many other GEO tasks as well.*

The publication, in 2005, of the Millennium Ecosystem Assessment Reports [7] marks a cornerstone of improved scientific and public recognition of the functions ecosystems provide for human well-being. This was due to the application of a relatively new and innovative concept which met a long-standing societal demand: how can we ensure not only the existence of ecosystems but also the continued supply of useful goods and services?

The Millennium Ecosystem Assessment demonstrated the degree to which human well-being, and its improvement during recent decades for many people, has depended on ecosystem functions and their constantly increasing use. These functions include the supply of food, fibre, shelter and other basic needs – but also more indirect functions such as the purification of waste water, the regulation of (regional) climate and the provisioning of surroundings of aesthetic value.

These functions are now routinely expressed as “ecosystem services”, a concept introduced by Gretchen Daily (Stanford University) and others only a few years before, although the actual method for quantifying them in a consistent and comparable manner is still under heavy debate. A key dispute takes place about the units for quantifying ecosystem service supply: should these be monetary and, if so, expressed differently for people living in different economies? A frequently expressed critique also states that valuation of ecosystems and their services is in contrast to the intrinsic value of ecosystems, and therefore unethical.

Some of these discussions may appear abstract/academic or else are carried out in the public discourse, e.g. between conservation NGO’s and other pressure groups. They nevertheless point to a steadily increasing research need, covering multiple disciplines.

Among the key questions being addressed in current research projects and new calls for research proposals are:

- Is the biological functioning of ecosystems affected by processes of global change (changing atmospheric CO<sub>2</sub>, climate change, land use change)?
- Does the change of ecosystem functioning modify the nature of the ecosystem significantly?
- Does significant change in ecosystem structure and functioning affect the well-being of people who depend, directly or indirectly, on the ecosystem – or is it in conflict with societal goals such as the preservation of biodiversity?

<sup>9</sup> THORPEX-Africa has developed comprehensive Science and Implementation Plans which may be downloaded from the WMO website (<http://www.wmo.int/pages/prog/arep/thorpex/>).



- What is the public perception of change in ecosystem structure and functioning?
- Are there non-linear “tipping points” in ecosystem dynamics (such as a level of tropical deforestation, or coral reef bleaching, which puts the entire ecosystem at risk of disappearance)?
- Can the impacts of changing ecosystem structure and functioning be mitigated in some way?

This (non-exhaustive) list of generic issues indicates clearly that ecosystem-related research has become a multi-disciplinary field.

These are described hereafter in more detail:

The research needs for the immediate future are nevertheless mostly well-rooted in classical fields:

- Ecosystem composition structure and function;
- Ecosystem dynamics;
- Nature of human impact on ecosystem dynamics;
- Delivery of ecosystem goods and services; and,
- Risks associated with ecosystem failure.

**Ecosystem composition, structure and function.** The taxonomy of species, the composition of their communities and food-webs, the physiological performance of organisms (plants and animals) in interaction with each other are all poorly known for most ecosystems (marine and terrestrial), despite many decades of research. While it is hard to give priorities in an area with massive need for additional knowledge throughout, it appears that the understanding of some ecosystems is currently being given specific focus, e.g. to tropical forests and marine biota (corals and deep sea ecosystems). This is partly a reflection of traditions and partly a response to the enormous threat for these systems.

**Ecosystem dynamics.** It is now well-established that most ecosystems are highly non-linear systems, capable of drastic changes in response to relatively linear forcings such as warming or acidification. The exact nature of change is sometimes difficult to detect and attribute. Many semi-arid ecosystems, for example, are affected by changing fire regimes, which may suddenly pass some threshold and change the nature into a different state. In some systems, fluctuations may be the “natural state”.

**Understanding the nature of human impact on ecosystem dynamics.** While some of the major drivers of change (greenhouse gas emissions, increasing atmospheric CO<sub>2</sub> concentration, changing temperature and rainfall, agricultural intensification, urbanization, deforestation) are known in principle, there is a shortage of knowledge about the underlying social processes and the role of main actors in them. This also limits the amount of management and policies that could be developed in order to avoid detrimental changes.

**Delivery of ecosystem goods and services.** Valuation of ecosystem goods and services has been made for many case studies, but the “full accounting” attempted by the Millennium Ecosystem Assessment has not been achieved. For some services, like for certain food items and fibres (wood), there are relatively good statistics, at least for the conventional money-based markets (and leaving out the values being obtained in subsistence systems). For many “less obvious” services, such as water purification and climate regulation, research is still underway to quantify both the relevant biological and physical mechanisms and the role they play for human well-being.

### **Avoiding risks (vulnerabilities) associated with ecosystem failure.**

For some major ecosystems or biomes, the level of threat is currently so substantial that massive failures are to be expected – most notably for many marine systems (tropical coral reefs, Arctic ice edge communities) but also on land in many areas of the humid tropics. Better assessment of these risks in a quantitative way (as undertaken for a small number of cases by EC-09-02) is a key and mostly unachieved research need, currently receiving attention by major funding agencies.

Many of the mentioned-above research areas are in substantial need for improved observations from satellites and other sources, as well as improved access to existing observations. These include better state-of-the-art descriptions of various parameters of the global biosphere (such as those addressed in EC-09-01) but need substantial expansion if they are to support any of the goals mentioned above.

Going much beyond biodiversity in a narrow sense, the GEO BON initiative (see below Section 3.9) has attempted to define the full range of needed observations, inter alia, through a dedicated group working on ecosystem services.

## **3.8 Agriculture**

*The GEO Work Plan 2009-2011 [1] includes two specific tasks on Agriculture: AG-06-02 – Data utilisation in fisheries and aquaculture, and AG-07-03 – Global Agricultural Monitoring. The latter includes the Task AG-07-03a (Global Agricultural Monitoring System), which has five main sub-tasks: 1) Global monitoring of agricultural production, facilitating reduction of risk and increased productivity at a range of scales; 2) Timely and accurate national (sub-national) agricultural statistical reporting; 3) Accurate forecasting of shortfalls in crop production and food supply; 4) Effective early warning of famine, enabling a timely mobilization of an international response in food aid; and, 5) Global mapping, monitoring and modelling of changes in agricultural land use, type and distribution, in the context of socio-economic and climate change. A number of other cross-cutting and thematic tasks have direct or indirect relationship with the Agriculture SBA.*

According to the UN Food and Agriculture Organization (FAO), in 2007, an estimated 923 million people were seriously undernourished. World population continues to increase, particularly in developing countries. Economic development in China is changing dietary habits and food demand. Increased globalization is altering access to and operation of the global markets. Climate change is expected to alter the global food supply, with implications for global and regional agricultural production and food security. Extreme weather events are impacting food availability and the stability of the food system, especially in rural locations where crops fail or yields decline, and in areas where supply chains are disrupted, market prices increase, and livelihoods are lost.

Some important agricultural areas appear to be experiencing significant deviations from the average climatic conditions under which the current farming systems were established. Such climate variability and change also stresses less vulnerable countries. For example, the heat wave of 2003 in France and Italy resulted in significant uninsured economic losses for the agricultural sector.

Agricultural monitoring, modelling and prediction can help in understanding and managing global food supply and demand. Monitoring and understanding of regional socio-economic and climate trends leading to improved prediction of their impact on agriculture and the national food supply is a high priority for governments.

Subsistence agriculture, determines the livelihood of millions of people in developing countries. This agricultural type is by far the most vulnerable

to climate and economic variability and change [8], and it is well recognized that poor, natural-resource dependent, rural households will bear a disproportionate burden of the adverse impacts of climate change. Changes in rainfall patterns and water availability are particularly likely to impact farmers living at the margins of areas suitable for agriculture. The occurrence of persistent drought can lead to devastating consequences for large numbers of people living in marginal agricultural lands. Food security for these people is a high priority for the international community. It should be noted, the consequences of climate change on agriculture are not all negative. In some regions a warmer climate will extend the current limits for certain crops and a longer growing season may lead to higher crop yields [9].

The FAO projects a ca. 60 percent decrease in the growth rate of food production by 2050. Considering that an 80 percent increase in agricultural production will be needed to feed the growing global population in the same period, it is clear that increased attention should be given to putting in place a reliable and transparent global agricultural monitoring system. This task is seen as a high priority for GEOSS. Such a discrepancy between supply and demand will undoubtedly require new croplands to be cultivated, many of which will replace tropical woodlands and forests in sub-Saharan Africa and Latin America [10]. This indicates a need for monitoring and modelling not only annual agricultural production but also changes in the distribution of agricultural lands.

In addition to the global population increase and climate change, the global food supply will be exacerbated by the rising cost of fertilisers (which is linked to the price of energy), competing demands for water for irrigation, political instability, national policies, and a changing distribution of pests and invasive species. Modelling the future trends in agricultural supply and demand is an important area for research requiring an integration of physical and social science.

Scientific research is clearly needed to develop the underpinning science of global agricultural monitoring using earth observations. Applied research is needed to take the scientific findings, techniques and methods, developed in the research domain and apply them to a given agricultural monitoring or modelling problem.

Basic and applied research, supported by modelling, field studies, and satellite observations, are needed to provide an improved understanding of global agricultural land use, productivity, and food supply in the context of global change.

Once the applied research and development has demonstrated reliability and robustness of a given technique, it can be transitioned to the operational domain. GEO with its focus on observations can both benefit from and contribute to the science of agricultural monitoring.

### **3.8.1 Global monitoring of agricultural production and timely and accurate national agricultural statistical reporting**

A primary goal of GEOSS is to coordinate comprehensive long-term observations needed for agricultural monitoring, integrating the necessary diverse components from the international Earth observing systems.

Methods have been developed over a number of years by the research community for the provision of agricultural production estimates. These methods include intensive ground-based area frame sampling and satellite-based monitoring. The latter has been seriously hampered by the limited availability of satellite data at the appropriate spatial resolution at critical times

during the growing season. The GEO Agricultural Monitoring Task has provided guidelines for the acquisition of coarse, moderate and fine spatial resolution satellite observations to meet agricultural monitoring needs. In some countries there is sufficient satellite data to meet these needs (e.g. India) however at the global scale a serious coordination effort by GEOSS is needed to provide timely global coverage. Similarly, applied research is needed to develop effective near real-time data streams from the current and future satellite systems.

Advances in the mapping and monitoring of soil moisture could lead to improvements in current crop yield models.

Research is needed to develop and validate satellite-based sensors and techniques for measuring and mapping soil moisture. Similarly the agricultural monitoring community could benefit from the fusion of optical and microwave techniques for monitoring crop growth and condition.

There are a number of approaches and methods for crop condition monitoring and yield prediction modeling. These approaches have been developed for different crop types and cropping systems. The agricultural monitoring Community of Practice is developing best-practices documents and could benefit from an inter-comparison of methods and approaches. To this end the GEOSS Agricultural Monitoring Task (AG-07-03a) has developed a series of Joint Experiments on Crops and Agricultural Monitoring (JECAM). These experiments will test the performance of different methods and data types in different cropping systems around the world. In support of these JECAM experiments, the space agencies are being requested to provide the optimum acquisition for data from multiple sensing systems. Advances are currently being made in the use of microwave systems for agricultural monitoring. Increased research is needed to test these methods on different cropping systems.

### **3.8.2 Effective early warning of famine, enabling a timely mobilization of an international response in food aid and accurate forecasting of shortfalls in crop production and food supply**

Famine early warning systems rely on a variety of field and satellite data inputs and a combination of physical and socioeconomic data. One of the important physical variables is rainfall. Obtaining accurate rainfall estimates in drought prone areas can be problematic particularly in Africa, where the distribution of rainfall is highly variable over short distances and the distribution of rain gauges is poor. In pursuance of the objectives of the IGOS Water Cycle Theme, GEOSS and WMO work together through the HARON (Hydrological Applications and Run-Off Network) project to increase the spatial distribution of rain gauge stations currently reporting in drought prone regions of Africa.

Further research is needed to develop robust satellite-based systems and methods for rainfall estimation.

Satellite monitoring of vegetation condition from coarse resolution sensors could be improved by research into methods for inter-use of data from multiple sensors, thus increasing the opportunity for cloud free coverage.

Current climate predictions are largely inadequate for food security systems (see 3.6 above).

Climate models are needed (i) that generate output at scales and with climate variables that are relevant to the impacts of climate change on different crop systems, and (ii) that include improvements in the key processes in crop models related to climate change (i.e. temperature, water stress, and their interaction with elevated CO<sub>2</sub>).

In particular benefits could be gained from more accurate 6-month lead climate forecast for drought prone regions. Recent efforts to enhance drought monitoring in the United States will need to be replicated for drought-prone regions of the world with populations and livelihoods at risk.

### **3.8.3 Global mapping, monitoring and modelling of changes in agricultural land use, type and distribution, in the context of socio-economic and climate change**

Economic development and population growth have led to extensive changes in the distribution of agriculture since the start of the satellite data record (ca. 1972 with ERTS-1). A number of local and regional studies have reported these changes but there has been no comprehensive and consistent global monitoring of these changes. With the opening up of the Landsat archive and the increase in computing capacity it is now possible to record these changes in a systematic way. We are however hampered by the sparsity of data for some periods and regions.

GEOSS needs to move quickly to coordinate and implement a global acquisition strategy at moderate resolution enabling the annual mapping of the extent of agricultural lands. The research community needs to further develop automated procedures and methods for monitoring agricultural land cover change.

One approach that is showing considerable potential is the fusion of moderate and coarse resolution data to provide improved detection and monitoring of change. Such methods should be applied to the historical record and current data as they are made available.

The availability of fine resolution satellite observations of better than 3 m provides new opportunities for direct observation and inference of land use, beyond the traditional mapping of land cover.

The current and future multiple stresses on agricultural lands mean

Increased coverage and availability of fine resolution data are needed in addition to research on automated techniques for land use mapping.

that further land use changes can be anticipated. Spatially explicit land use modelling provides a tool for exploring various scenarios of change and assisting decision makers in long term planning. These tools are currently being developed in the research domain.

A new generation of integrated dynamic Earth System models (Integrated

Further research is needed to develop regional, spatially explicit, process models of land use change, to project agricultural expansion, intensification, and abandonment and to model the potential impacts of these changes on the major biogeochemical cycles, land-atmosphere exchange of water and energy and human population dynamics.

Assessment Models) incorporating both physical and socioeconomic factors is needed to better project changes in regional food supply and demand resulting from a changing climate and to inform mitigation and adaptation options. Effective adaptation will require an integrated view of climate change issues, including climate variability and market risk in the context of regional economic and sustainable development. It will require effective institutions for determining agricultural production and implementing adaptation measures at a range of scales. Tariffs and subsidies that strongly influence the global supply of food will inevitably change as governments respond to shifting markets and changes in global agricultural supply and demand, resulting in part from changes in regional climate.

Improved end-to-end, coupled biogeochemical, hydrologic, and economic models are needed to address the impacts, feedbacks, and costs of different agricultural land use change (e.g. extensification or abandonment) and different land use mitigation options to sequester carbon (e.g. conservation agriculture, no-till agriculture, shade cropping), to establish the impacts of agricultural intensification and increasing fertilizer use, and to examine the trade-off between using crops for food or for biofuel.

Similarly improved scientific understanding is needed to examine the trade-off between using crops for food or for biofuels and the impacts on food prices, secondary land use and soil erosion.

Field experiments will be needed to parameterize these models and to quantify the net carbon sequestration and the water use and quality implications associated with different mitigation and alternative energy options.

Supporting the above science has significant implications in terms of infrastructure.

Infrastructure needs include increased computational capacity to run higher resolution climate models with regional specificity and improved land surface satellite-based observations.

## 3.9 Biodiversity

*The GEO Work Plan 2009-2011 [1] includes only one Biodiversity Task, namely BI-07-01 – Developing a Global Biodiversity Observation Network. There are a number of other cross-cutting and thematic tasks which have direct or indirect relationship with the Biodiversity SBA. There was no IGOS biodiversity theme, though some elements of biodiversity were indirectly addressed under the Coral Reefs, Coastal, Ocean, and Land themes.*

This Section deals separately with the Land and Marine Biodiversity, which involve diverse communities, imply diverse research tools and belong to diverse institutional frameworks. This does not deny the strong existing commonalities between both fields which are gathered under the same SBA, and work together at implementing the GEO Biodiversity Observation Network (GEO BON). Plans for this network focus on biodiversity at the levels of ecosystems, species, and genes, as well as on the crosscutting theme of ecosystem services. For each of these, observations will seek to identify: changes in state over time, drivers of change, trends in these changes, and the impacts of changes. GEO BON will incorporate satellite, airborne, and in situ observations of terrestrial, freshwater, and marine systems in a framework uniting top-down global and regional scale assessments with bottom-up local and landscape/seascape scale assessments.

### 3.9.1 Land Biodiversity

Four broad research areas are essential for the advancement of the GEO Biodiversity Observation Network (BI-09-01a) over the next decade: biodiversity proxies; indicators; discovery; and, observation technologies.

#### 3.9.1.1 Biodiversity Proxies

It is estimated that only 10 percent of all species are scientifically described, and the geographical and taxonomic distribution of this sample is very biased. Thus for the foreseeable future we will rely on proxies to inform us

about what is happening to biodiversity in general. In the past, these proxies have been largely taxonomic (e.g. birds representing all biodiversity). New approaches promise a much more robust set of proxies. Metagenomics is one such approach. It involves determining the DNA sequences present in entire biological communities, thus bypassing the species impediment – especially useful where the species concept is weak (such as for microbes). Metagenomics is a fundamental measure of biodiversity, but also holds the possibility of being predictive of ecosystem function (“ecogenomics”).

Continued investment in gene-sequencing infrastructure is needed, and directing some of it explicitly towards biodiversity-related questions is indicated.

A second “proxy” approach is to focus on the drivers of biodiversity change. Two driver-proxies are especially important: loss in connectivity and scale in habitats, and the Human Appropriation of Net Primary Production (HANPP).

The mechanisms and relations through which these processes lead to biodiversity loss are fruitful areas of research that would allow the observable changes to be related to their likely consequences. Both of these drivers require investment in observational and computational infrastructure, and the support of some large scale experimentation to establish the functional links between the drivers and biodiversity persistence.

### 3.9.1.2 Indicators

For biodiversity primary observations to become useful decision support information they typically need to be combined into a small number of indicators. The theoretical disarray in this field is obvious in the 2020 biodiversity target indicator set.

Much work needs to be done to develop and establish biodiversity indicators that are scientifically rigorous, robust to the different circumstances worldwide, sensitive to the changes underway, and easily communicable to users. Little infrastructure is needed but multidisciplinary project support is.

### 3.9.1.3 Biodiversity discovery

The majority of biodiversity is either unknown, or incompletely documented. It is not necessary, for practical purposes, to know it all – but we are currently very far from the level of adequate knowledge, especially for functionally important but poorly-studied groups such as microbes and invertebrates. New gene-based techniques and bioinformatics systems are making the process of discovery much more efficient.

A targeted approach to filling important spatial and taxonomic gaps is called for. This requires some infrastructure (facilities for handling and storing specimens and doing taxonomic investigations, investment in screening procedures such as Barcode of Life). Systematic classification and mapping efforts at the ecosystem level are also essential, and a much closer integration of the rapidly-expanding gene-level data generation with its spatial, taxonomic and ecosystem context.

The US-09-03b, US-09-03d, EC-09-01a and EC-09-01b tasks are relevant here.

### 3.9.1.4 Technologies for biodiversity observation

Biodiversity is unusual among the GEOSS SBAs in the degree to which it depends on in situ observation by humans. This imposes limits to the rate and location of data capture and introduces errors due to observer bias.

Advances in communications technology, imaging and pattern recognition and machine-learning will allow a much higher degree of automation of biodiversity observations – ranging from cell phone camera networks operated by citizen scientists, to acoustic signal-processing systems for vertebrate census, to robotic systems for capturing label data in museum collections. The key investment issues here are to engage the technology and engineering community in the solutions to the biodiversity observation problem.

The development of standardised field observation protocols falls under this general heading as well.

## 3.9.2 Marine Biodiversity

### 3.9.2.1 What is marine biodiversity?

The oceans cover 70 percent of the surface of the earth and contain an even larger part of the biosphere, with an average water depth of 3.8 km and a subsurface sedimentary biosphere of ca. 1 km depth on average. Life originated in the sea, marine biodiversity is nearly three billion years older than terrestrial biodiversity and has been evolving in an environment that is very different from land. As a consequence, although species diversity is perhaps lower in the oceans than on land, genetic diversity and the diversity of higher taxa are undoubtedly much higher.

One important feature of marine biodiversity is the dominance of microbial species and processes in the oceans. The microbial component accounts for 50-90 percent of the marine biomass. One litre of seawater contains on average 10<sup>9</sup> Bacteria, a similar amount of Archaea, an order of magnitude more viruses and ca. 10<sup>3</sup> microbial eukaryotes (organisms with a cell nucleus, including all plants and animals). The number of bacterial “species” in one litre of sea water is ca. 20,000 and in one kg of surface marine sediment probably much more than that, but mostly unknown. Moreover, the “species” composition of Bacteria and Archaea is very different in different marine ecosystems and shows large variations in different marine environments on different time scales of days, months and years.

Since microbes “rule the world”, i.e. regulate biogeochemical cycles and thus climate and climate change, it is of utmost importance not only to determine their biodiversity per se but also to understand their metabolism and interactions, and the changes thereof as related to human perturbations, including climate change and acidification.

This is a tremendous task and it also holds, for larger organisms living in the water column and on hard substrates and in sediments of the sea floor. Eukaryote organisms vary enormously in size from less than 10 µm to over 100 m for certain kelp species. But here as well, most of the biomass is contained in small organisms. Many grazers in the zooplankton, dominating marine food webs sustaining the larger animals, are barely visible to the naked eye. As for the microbes, a large part of this marine biodiversity is still unknown and new species are routinely found, even in coastal areas.

Large organisms are important to society as they present ecosystem goods and services such as food, carbon sequestration (blue carbon) and natural products important to human society. Top-down regulation of marine food



webs may be as important as bottom-up regulation and the elimination of top predators and top herbivores such as large mammals, birds, marine reptiles, fish and sharks may be changing the ocean's ecosystems as intensely as temperature rise, pollution and eutrophication or acidification.

### 3.9.2.2 Biodiversity loss

The effects of pollution and eutrophication in coastal areas and enclosed seas worldwide have been documented since the sixties of the previous century and much information exists. Biodiversity loss in the open oceans is mostly unknown, but has been documented for commercial species, top predators and herbivores. One striking example of a change in an ecosystem occurred when in the previous centuries large and also smaller whales and pinnipeds were hunted to near extinction. In the Southern Ocean the disappearance of whales led to much larger stocks of krill which benefited penguins and sea mammals and birds (and probably fish). Similar changes can be expected with the present overfishing of large predatory fish and sharks, of which some stocks are now reduced to a fraction of their numbers only fifty years ago. In a cascade of events down the food chain the disappearance of big fish could lead to smaller fish becoming more abundant, zooplankton less so and phytoplankton again more. But since humans are now also more and more fishing away smaller fish species (fishing down the food chain), also the opposite may happen. This uncertainty and the interaction between top down and bottom up regulation of food webs make prediction of biodiversity loss and its effects very difficult with the present knowledge.

A relatively new phenomenon is the rapid spread through human activities of species to areas where they did not exist before. Especially maritime transport and aquaculture are important activities which lead to a near continuous invasion of marine habitats worldwide by so-called alien or exotic species. In many cases these invasions are not successful but when they are, they can dramatically change marine ecosystems. Well-studied examples such as the invasion of the Black Sea and later the Caspian Sea by the comb jelly *Mnemiopsis leydii* or the rapid spread of the Japanese oyster in European waters show that ecosystems can be completely changed in a matter of a few years by these invasions.

Besides overfishing and the introduction of exotic species, climate change in itself is changing marine biodiversity. The increasing surface water temperatures, small as they are, have triggered the northward extension of populations in the northern hemisphere over many hundreds of kilometres over the last decades in the case of zooplankton in the northern Atlantic or fish species along the European margin, including the North Sea. For Europe this has in fact led to an increase in marine biodiversity over the last few years, as the southern communities are more species-rich than the northern ones they replace. On the other hand, northern species are often larger than southern species so that food webs not only become more species-rich but also contain smaller species in general and this leads to a reduced productivity.

Another effect of increasing CO<sub>2</sub> is acidification: pH during the 21st century is expected to decrease about 0.3 pH units. This will raise the saturation horizon for aragonite and calcite upwards and will change the chemical environment for calcifiers such as coccolithophores in the phytoplankton, forams and pteropods in the zooplankton and corals, coralline algae and molluscs in the benthos.

### 3.9.2.3 Research Challenges

Because much diversity is in microbial species and in cryptic environments, marine biodiversity is still being explored and it is difficult to make good estimates of species numbers. A few years ago about 230,000 species of marine

plants and animals were scientifically described, and this number grows linearly each year.

In the microbial domain through genomic analyses it has become clear that both in small eukaryotes and in Bacteria and Archaea the number of species is immense. Add to this the viruses and it becomes clear that microbial marine biodiversity will need inventorying and classification for many years to come. Using metagenomics at least the genetic diversity of microbial communities can now be evaluated. In a few years time it will be possible to obtain complete genomic information from water and sediment samples at a reasonable cost, which will allow for a much more intense exploration than is possible now.

The need for taxonomic research on higher organisms has been stressed repeatedly over the last years and the loss of taxonomic expertise has been countered by several initiatives, but in general this decline is proceeding. There are now higher marine taxa for which there is no expert alive in the world and the taxonomic literature on many groups is outdated. This problem can only be solved by worldwide cooperation and specialization between taxonomic institutes, a process that is increasingly taking place.

Charting existing marine biodiversity and its changes at the relevant scales of space and time requires an unprecedented effort that can only be successful if regionally and globally coordinated and supported. This effort has to deal with bringing existing data sets in the picture, making them accessible and stimulate research to exploit them. The information on changes in biodiversity in the marine environment is very scattered and anecdotic. The data are in many different data bases and not easily accessible, even not for scientists let alone policy makers or the public at large.

Besides making much better use of existing data a system of exploration and monitoring of marine biodiversity at the right scales of space and time has to be developed. Many monitoring efforts exist but they are uncoordinated between them. A regional monitoring system must make optimal use of existing schemes and methodologies as for instance those which will become legally required in the EU in the coming years. A global monitoring system will have to be based on governmental support and experience from the past has shown this to be a very slow process.

Still, the basic elements for such a global system exist. There are hundreds of marine stations from institutes and universities worldwide. Together they can support a basic monitoring system similar to weather stations for biodiversity. The overwhelming majority is coastal, but some open ocean observatories exist (Hawaii, Bermuda, the Continuous Plankton Recorder, Census of Marine Life) as well as some on the deep sea floor (Neptune, Esonet ...). Also some networking between those marine stations is already in place, in Europe, the US, Japan, Australia, East Africa and so on and this may be developed further to a global network of marine stations.

Marine stations can cover biodiversity hot spots, obtain long-term data series, can detect and monitor the spread of invading species and can serve for ground-truthing of remote sensing information. Remote sensing from airplanes and satellites will be indispensable to obtain synoptic pictures of biodiversity elements, such as the extension of coral reefs or seagrass meadows in shallow water, and blooms of phytoplankton in the open ocean as well as in coastal regions.

Remotely sensed information can also be helpful in describing and understanding microbial processes. Primary production in the upper surface layers can be estimated from algorithms based on ocean colour. This information is restricted to a very shallow surface layer, but by using in situ field studies, e.g. using the information from the Argo floats, one may be able to correlate properties of the ocean surface to the deeper water layers and the

sea floor. Some examples exist of detecting anoxic events by remotely spotting sulphide in surface waters, e.g. in the Benguela upwelling offshore Namibia.

Observing and mapping the detailed structure of the deeper water column and of the sea floor is rapidly advancing by new acoustic techniques (e.g. multibeam sonar) and by tagging programmes in which large, deep diving animals such as sea elephants are equipped by sensors that can transmit data on the water column to satellites every time they surface.

#### **3.9.2.4 Linking marine biodiversity and ecosystem functioning**

The second main research question is the link between biodiversity and ecosystem functioning. This can be addressed at the level of genes, species and habitats or ecosystems.

At the genetic level through the venue of genomics and more recently proteomics and transcriptomics, a true revolution in our view of marine ecosystems has occurred. We are now able to detect the genes responsible for key processes such as nitrogen fixation or photosynthesis. Remarkably, genes have been detected before the organisms that bear them have been found.

At the species level, we have good knowledge on a number of species that are important in marine ecosystems because they are key species in biogeochemical processes or because of their commercial importance. The questions whether there is redundancy in species occupying similar niches or whether assemblages of species perform better than individual species have been mostly unanswered until now. Only a relatively small number of experiments in controlled conditions in which species were added to, or eliminated from, communities have been performed. In these experiments ecosystem functions such as mineralization and productivity were linked to the occurrence and performance of particular species.

A still mostly unexplored but challenging question is how habitats can be linked to ecosystem functioning.

Habitats are predictors for species and genetic biodiversity and are the units on which conservation of marine environments is based, but they have been rarely assessed in terms of ecosystem functioning. It would require a major scientific effort in which habitats are compared worldwide and linked to some measure of functioning, such as primary production, mineralization or denitrification, to chart the functional role of habitats. Very little research has been conducted on this yet and what has been done is mainly in coastal areas open to manipulation and experiments. In the open ocean, only the iron fertilization experiments may be considered as experiments on the relationship between productivity and biodiversity.

## 4. Expected Scientific Benefits associated with GEOSS

Each subsection hereunder includes a short account of the expected benefits for science and research that would stem from a fully-developed GEOSS in the corresponding area. To the extent possible emphasis is placed on the benefits that would evolve from the integrated use of a “system of systems”, including a combination of diverse observing components, as opposed to the direct use of application-tailored, dedicated observing systems.

### 4.1 Disasters

According to the GEOSS 10-Year Implementation Plan, “*GEOSS implementation will bring a more timely dissemination of information through better coordinated systems for monitoring, predicting, risk assessment, early warning, mitigating, and responding to hazards at local, national, regional, and global levels*”.

As an essential stage of disaster management lessons learned from past events include the requirement that suitable distributed data sets, as exhaustive as possible, be easily accessible for scientific and research purposes. Such data sets would encompass multiple types of information, including inventories of human and economical assets at risk, at scales commensurate with hazards themselves. This is especially the case in extreme hydrological events, for which an archive of corresponding meteorological, hydrological data as well as flood mapping (see for instance the precursory work of the Flood Observatory at Dartmouth) during the event is becoming available. This will foster the development of integrated approaches (including observation, experiment, theory and modelling) based on the multi-parameter approach and taking into account coupling mechanisms, as encouraged by the GEO Work Plan. Systematic multiple observations of hazard-prone areas may nurture scientific research and open new avenues, for instance preferred, systematic fire paths, or understanding effects of man-made changes to the landscape, including hazard prevention measures (e.g. flood protection dams).

It is well documented that climate change may induce more frequent, newer or stronger natural extreme events; conversely, effects of disasters on climate change and ecosystems are less well known. Most pronounced consequences of forest fires induce potential effects on climate change. Only in the past decade researchers have realised the important contribution of biomass burning to the global budgets of many radiatively and chemically active gases such as carbon dioxide, carbon monoxide, methane, nitric oxide, tropospheric ozone, methyl chloride and elemental carbon particulate. Biomass burning is recognised as a significant global source of emissions contributing as much as 40 percent of gross carbon dioxide and 30 percent of tropospheric ozone. Most of the world burnt biomass matter is from savannas, and because two-thirds of the Earth’s savannas are in Africa, that continent is now recognized as the “burnt centre” of the planet. Biomass burning is generally believed to be a uniquely tropical phenomenon because most of the information we have on its geographical and temporal distribution is based on the observation of the tropics. Because of poor satellite coverage, among other things, little information is available on biomass burning in boreal forests, which represent about 29 percent of the world’s forests. Knowledge of the geographical and temporal distribution of burning is critical for assessing the emissions of gases and particulates to the atmosphere.

Experiments conducted over the past decade have shown that it is possible to study the dynamical behaviour of the Earth from space. Satellite-based measurements are among the most practical and cost-effective techniques for producing systematic data sets over a wide range of spatial and temporal

scales. The combination of space-based and surface measurements provided by GEOSS will provide a better understanding of the dynamics of the solid Earth. The dynamics of the solid Earth are, in fact, quite varied: tectonic plates shifting, coastal erosion, and volcanic eruptions occur from geologic timescales to sudden, catastrophic moments.

In particular dense surface deformation data will lead to a better understanding of tectonic mechanisms; dense and relatively continuous space-based data may lead to a more precise understanding of how exactly the magma behaves close to the Earth's crust.

Eventually the scientific exploitation of the wealth of data collected by planned and future missions will enable a better understanding of underlying processes, such as the water cycle, and the discovery of new precursor signals (for instance electromagnetic or thermal anomalies as earthquake precursors) should not be excluded. The scientific analysis of data collected by France's Demeter space-borne experiment devoted to the detection of earthquake precursor signals is ongoing. Remote sensing missions like the European Space Agency's SMOS will contribute to a better understanding of the water cycle. Advances in satellite altimetry may allow for effective observations of ocean water level (tsunamis) and major river flow (floods).

## 4.2 Health

The GEOSS 10-Year Implementation Plan states that *"GEOSS will improve the flow of appropriate environmental data and health statistics to the health community, promoting a focus on prevention and contributing to continued improvements in human health worldwide"*.

Facing an increasing population in a rapidly changing climatic, economical and mobility context, health stakeholders are looking for new information and means to help them set up adaptation strategies. Earth observation (EO) data can already provide health authorities and stakeholders with relevant information on various issues such as climate, environment and anthropic evolutions. Innovative models integrating EO and in situ data have shown promising possibilities for being integrated in Early Warning Systems (EWS) for air borne, water borne or vector borne infectious diseases, with predictive risk maps.

The societal value of GEOSS for the health sector will largely depend on its expected ability to ease access to satellite data at various scales, from low to very high resolution, and to facilitate their integration into innovative predictive models, providing health users with adapted products suitable for optimizing their action.

Demonstration projects and innovative products for health development have to be encouraged, but the sustainability of the projects remains a challenge. Building capacities for new users of remote sensing, or for people using products integrating remote sensing data, is another challenge that GEOSS will help achieve.

A fully-developed GEOSS would definitely expand the use of Earth observation for health and contribute to health adaptation strategies and plans. For example, space-based measures will produce new views of air pollution and the extent of human exposure, possibly leading to better opportunities to protect public health. Concerning respiratory diseases key data needs include improved measures for data quality assurance and control, validated correlations with health outcomes, and confirmation that remote-sensing data accurately represent exposures on the ground. Remote sensing could help fill gaps in existing exposure data. Remotely-sensed observations of airborne particulates and bio-allergens could be correlated with asthma prevalence. Earth observation data could also be used in support of cardiovascular chronic disease research.

### 4.3 Energy

According to the GEOSS 10-Year Implementation Plan “*GEOSS outcomes in the energy area will support: environmentally responsible and equitable energy management; better matching of energy supply and demand; reduction of risks to energy infrastructure; more accurate inventories of greenhouse gases and pollutants; and, a better understanding of renewable energy potential*”.

As the demand for energy is rapidly rising worldwide, so is the need for geo-information.

Global and consistent data from EO satellites can help energy managers optimize their activities across the whole life-cycle of energy exploitation – from exploration of natural resources up to the siting/design of power plants and the support of their operations–, thereby accelerating the realization of the full societal value of GEOSS for the Energy sector.

In particular, with the rapid growth of renewable energy, the need for resource assessment, at different temporal scales (from long-term time series to real-time monitoring) and spatial scales (from local to global), is rapidly increasing.

One key issue is related to the integration of renewable energy – being an intermittent source by nature – on existing energy supply systems. Accurate and timely nowcasting/forecasting of renewable electricity production (e.g. wind, solar, run-off forecast) is especially important for the management of the new generation of ‘Smart Grids’ optimizing the balancing of electricity demand and production. Errors in the forecast of potentially available resources would induce errors in the load forecast, which can then significantly affect the price of electricity through trading and also increase the risk of grid-failures (e.g. the 14 August 2003 black-out in the U.S.). In the case of solar energy, facilitated access and improved spatial/temporal availability of environmental information (e.g. aerosol load, snow/cloud cover, humidity and air temperature) would accelerate new scientific developments (e.g. improved distribution functions or direct irradiances for concentrating solar power technologies) to estimate solar energy potentials and electricity production forecasts [11a, b and c].

A fully-developed GEOSS, combined with appropriate information technologies (e.g. meter technology), would provide the necessary “intelligence” to a fully distributed (but integrated) energy management system (e.g. the Internet of energy), optimizing the production and distribution of energy worldwide.

### 4.4 Climate<sup>10</sup>

As stated in the GEOSS 10-Year Implementation Plan “*The climate has impacts in each of the other eight societal benefit areas. Coping with climate change and variability demands good scientific understanding based on sufficient and reliable observations. GEOSS outcomes will enhance the capacity to model, mitigate, and adapt to climate change and variability. Better understanding of the climate and its impacts on the Earth system, including its human and economic aspects, will contribute to improved climate prediction and facilitate sustainable development while avoiding dangerous perturbations to the climate system.*”

The importance and visibility of climate information systems that provide products and services relevant to climate-related risk management and decision-making has risen dramatically in the last few years, a trend that is likely to continue. At the 3rd World Climate Conference (WCC-3) the World Meteorological Organization (WMO) and its partners agreed to establish a Global Framework for Climate Services (GFCS) to strengthen the production,

<sup>10</sup> This section draws on material from a report on Applications and Services presented by C. Vera, J. Slingo and F. Semazzi at the 31st meeting of the Joint Scientific Committee of the World Climate Research Programme, Antalya, Turkey, 15-19 February, 2010.

availability, delivery and application of science-based climate predictions and services on all timescales from months to decades.

Progress made by climate research in observing, understanding and predicting seasonal-to-decadal climate variability, along with potential human-induced climate changes, already provides a strong foundation for the delivery of a wide range of climate services. WCC-3 [12] concluded, that “major new and strengthened research efforts are required to increase the time-range and skill of climate prediction through new research and modelling initiatives; and to improve the observational basis for climate prediction and services, and the availability and quality control of climate data.”

Climate services must be understood as part of the whole process from basic, underpinning research, through applied research to the providers of predictions and the products and services that flow from those predictions. Society is increasingly vulnerable to hazardous weather and climate extremes, be it heavy rainfall and flooding, high winds, storm surges, sea level rise, prolonged drought, heat waves or poor air quality. Many of the most dangerous effects of climate change may come through the increased incidence and/or intensity of extreme events, and communicating those risks to society presents significant challenges. A key need for any climate service is the provision of timely and reliable forecasts of the likelihood of hazardous weather and climate. Detecting, attributing and predicting possible changes in the frequency and characteristics of hazardous weather and climate as the planet warms up require some major advances in observing, modelling and prediction systems. Defining what hazardous means, for whom and where, will require detailed understanding of the vulnerability of society and key systems (e.g. food and water) to changes in the patterns and characteristics of weather and climate. And it will need to consider how interactions with other components of the Earth system act to mediate the impacts of hazardous weather and climate (e.g. soil moisture in intensifying heat waves, atmospheric chemistry in linking blocking to poor air quality, oceans and the cryosphere in determining sea level rise), along the underpinning research required to represent those processes.

Fig. 3 A schematic of the flow of the climate information system, as basic research feeds into applied and operational research and the development of climate services. The system is built on the climate observing system that includes the analysis and assimilation of data using models to produce analyses and fields for initializing models; the use of models for attribution and prediction and with all the information assessed and assembled into products and information that are disseminated to users. The users in turn provide feedback on their needs and how to improve information.

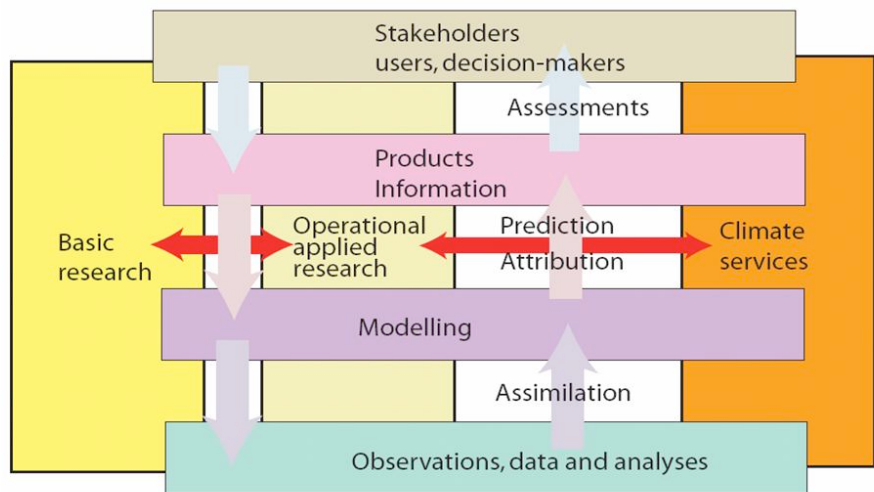


Figure 3 emphasizes the essential role that observations, research, modelling and prediction systems must play, but especially the dialogue that must be maintained between the developers and users of climate services, and those engaged in the fundamental research and delivery of predictions. It will only be when researchers embrace this concept and set their research in the context of societal needs that real progress will be achieved. GEO and GEOSS offer a unique opportunity for this to happen, through enabling the research community the free, open and timely access to the full suite of necessary observations.

## 4.5 Water

The GEOSS 10-Year Implementation Plan defined the following target for Water: *“Water-related issues addressed by GEOSS will include: precipitation; soil moisture; stream flow; lake and reservoir levels; snow cover; glaciers and ice; evaporation and transpiration; groundwater; and water quality and water use. GEOSS implementation will improve integrated water-resource management by bringing together observations, prediction, and decision-support systems and by creating better linkages to climate and other data. In situ networks and the automation of data collection will be consolidated, and the capacity to collect and use hydrological observations will be built where it is lacking.”*

Again this section includes specific paragraphs devoted to the benefits expected from GEOSS for cryosphere research.

### 4.5.1 Water

Water resources management is a political and socio-economic issue as well as a scientific, technological and engineering concern. For example, water resource allocation affects the structure of industry and the regional environment. Strong pressure for land-use expansion associated with a rapid population increase has constrained flood control options. To make a sound decision in water policy responding to changing political and socio-economic needs and demands, it is vital to develop a comprehensive risk assessment method that covers political and socio-economic aspects as well as natural scientific aspects. Risks to infrastructure lifecycles should be also considered. The lifetime of a water supply facility, including water channels and lines, is 30 to 40 years. The facilities constructed and expanded in the 1960s with the expansion of cities will soon reach the end of their designed lifetimes. There is an increasing concern that the failure of the water supply system due to facility deterioration may result in a tremendous socio-economic disaster.

Model simulations and other analyses suggest that total flows, probabilities of extreme high or low flow conditions, seasonal runoff regimes, groundwater-surface water interactions, water quality characteristics, etc. could all be significantly affected by climate change over the course of the coming decades. It is virtually certain that there will be changes in global quantity and distribution of precipitation and runoff. But significant uncertainties remain as regards local and regional impacts. This is where GEOSS will make a difference.

With the socio-economic background of water described above, it is important to develop a comprehensive assessment system that can quantify socio-economic impacts induced by climate change on comprehensive societal benefits, including complacency about the risks to life and environmental safety. The method should be able to reflect the effects of climate prediction uncertainty in an appropriate way and contribute to a rational definition of socio-economic objectives.

Elaborate preparation and a well-coordinated water resources management system are needed for addressing extremes resulting from large water cycle variations and modifications associated with climate change. While the variations and changes are global issues, damage due to extreme events associated with climate change depends on local vulnerability. To address these multi-scale problems, a proactive regional management body should be formed to promote consensus building and mediate conflicts of interests in addition to centralized governance approaches. This governance should be a sustainable, resilient and holistic system that includes the functions of monitoring, assessment and evaluation, and re-examination.

People tend to accept well-validated data with clarified accuracy and to use them for sound decision making. For example, the climate projections produced with a number of leading-edge models and described in the



4<sup>th</sup> Assessment Report of IPCC [4] have to a large extent led to the end of the arguments about the causes of global warming and have stimulated discussions of mitigation and adaptation measures. There is a need to create knowledge to be shared worldwide by constructing infrastructure which can provide data that are quality-controlled and validated by integration. Physical science data and information are being translated into socio-economic impacts that are easily understood by non-experts thereby increasing public awareness of environmental problems. In addition, participatory monitoring activities are encouraged when their contributions to socio-economic benefits become apparent through integration of the data into usable information. One also needs to disseminate data and information that brings awareness of the impacts and opportunities.

To address water-related issues and socio-economic impacts caused by water-related extremes, such as floods, droughts and landslides, water scarcity, river and water environment degradation, and the effects of climate change overall, it is strongly recommended that community of practices be activated through dialogues among policy makers, practitioners, laymen and scientists, based on global Earth observations and models using physical, chemical, biological and socio-economic information and capacity development programs.

#### 4.5.2 Ice

The development of a more complete observing system for the cryosphere through GEOSS is both timely and essential, particularly given the recent dramatic changes occurring within the cryosphere and their broad ranging implications for society. Despite the fact that the cryosphere is known to be an important component of the climate system, and that the economic importance of adaptation to climate change is becoming indisputable, surface networks for individual cryospheric elements are generally declining and there are serious problems with satellite data continuity and acquisition. Actions are required to develop and maintain the observing systems. Furthermore, improved monitoring of the cryosphere through the integration of surface- and space-based observations is essential for understanding global climate change, optimizing knowledge of current environmental conditions and exploiting this information for predictive weather, climate, and water products and services.

A fully-developed GEOSS would provide the information needed to address the following science questions:

- What will be the magnitudes, patterns and rates of change in the terrestrial cryosphere on seasonal to century timescales in the 21st century? How will this affect the water cycle?
- What will be the major socio-economic consequences of changes in the cryosphere?
- What is the contribution of glaciers, ice caps and ice sheets to changes in the global sea level on decadal-to-century time scales?
- What will be the nature of changes in sea ice distribution and mass balance in response to climate change and variability?
- What will be the impact of changes in the cryosphere on the atmospheric and oceanic circulation?

A robust GEOSS will support an integration of diverse observation types. This is a formidable task, given that cryospheric surface networks and satellite systems tend to operate individually, focusing entirely on the element that they are supposed to monitor. Their observations do not support, as much as they could, the generation of integrated cryospheric products. The “system of systems” concept is intended to improve synergy between observing systems, producing a more comprehensive picture of the cryosphere. One

example of such synergy for the cryosphere is the National Snow Analyses, produced operationally for the conterminous U.S. by NOAA's National Weather Service. A land surface modelling and data assimilation framework, forced by downscaled numerical weather analyses, is used to fuse all available ground observations of snow depth and snow water equivalent (SWE), airborne SWE observations, and observations of snow cover from multiple satellites into a comprehensive suite of hourly snow information products. A fully functioning GEOSS would provide the motivation and justification for other integrated analysis systems.

Climate reanalysis systems, e.g. the European Centre for Medium-Range Forecasting's (ECMWF) ERA-40 project, are another example of combining diverse data from multiple systems for a product whose benefit is greater than the sum of its parts. Such systems exploit the fact that each component of the observing system has advantages and disadvantages. For example, satellites observe sea ice extent and concentration very well; in situ networks do not. Conversely, satellites and models do not estimate ice thickness very well, while in situ measurements of this parameter are very accurate. However, one of the key obstacles to the success of reanalysis systems comes back to the individual components: error characteristics of data are often not well known, there may be multiple products for the same parameter, and parameterizations of some model physics may be inadequate. Nevertheless, operational (near real-time) and climate reanalysis projects may offer the best opportunity for a system of systems approach. The development of such information integration methods is a key for exploiting the cryosphere observing system, and should be a priority for GEOSS.

## 4.6 Weather

The GEOSS 10-Year Implementation Plan states that *“The weather observations encompassed by GEOSS are based on the requirements for timely short and medium-term forecasts. GEOSS can help fill critical gaps in the observation of, for example, wind and humidity profiles, precipitation, and data collection over ocean areas; extend the use of dynamic sampling methods globally; improve the initialization of forecasts; and increase the capacity in developing countries to deliver essential observations and use forecast products. Every country will have the severe-weather-event information needed to mitigate loss of life and reduce property damage. Access to weather data for the other societal benefit areas will be facilitated.”*

The GEO Work Plan offers several examples of the benefits that GEO and GEOSS can bring to scientific research devoted to weather forecast, with potential applications for society. Two such examples are described hereunder.

### 4.6.1 TIGGE (the THORPEX Interactive Global Grand Ensemble) and the development of a Global Interactive Forecast System (GIFS) for weather

Development of TIGGE and GIFS by the WMO represents an important contribution to scientific research, as well as a significant input to a number of GEO Tasks related to risk management, early warning systems, major hazards and associated impacts. As a first step it is expected that TIGGE will develop initial probabilistic products related to tropical cyclones and precipitation forecasting associated with high impact weather events. These prototype products will be developed to improve the prediction of high-impact weather, based on ensemble forecasts from the TIGGE data providers. The products will also be evaluated and assessed for possible operational implementation in later stages of the project. They may form the early products from an initial GIFS.

A benefit of making TIGGE data widely available to the research community is that universities are expected to provide valuable contributions by helping

to develop verification and post-processing methods. It has been proposed that, for timely implementation of research findings into operational practice, the scientific research and initial technical developments necessary for the development of GIFS proceed in parallel. Initial operational implementation will be planned to proceed through the Severe Weather Demonstration Forecast Projects (SWFDPs) set up by the WMO.

#### 4.6.2 THORPEX-Africa

The THORPEX-Africa Initiative seeks to improve the prediction of high-impact weather and help reduce vulnerability to climate variability and change in Africa. It is designed to both accelerate predictive skill of high impact weather in Africa and help realize the related benefits for African society and the economy through a set of demonstration projects. It is intended to help support the 21st century African forecasting offices to meet these needs.

Improving high impact weather forecasts in Africa is very important because this region is amongst the most vulnerable areas of the world to severe weather. However, it remains challenging because:

- The in situ observing system over the region is generally poor;
- Weaknesses in communication infrastructure in most African countries have created a barrier to disseminating forecast products;
- Africa is among the regions where the current numerical models and forecasting systems have the highest deficiencies; and,
- Development and update of forecasting techniques are not regular, reducing the ability of forecasters and end-users to fully benefit from recent improvements in forecasting systems performance.

It is hoped to generate significant socio-economic benefits in Africa from demonstrating improvements in forecasting the following high impact events:

- Heavy rainfall and floods due to severe storms;
- Tropical cyclones;
- Severe extra tropical events;
- Dry/wet spells;
- Sand and Dust episodes;
- Severe winds due to tropical cyclones, severe storms, cyclogenesis;
- Early or late onset and withdrawal of the seasonal rainfall; and,
- Extreme temperatures.

### 4.7 Agriculture

According to the GEOSS 10-Year Implementation Plan, *“Issues addressed by GEOSS will include: crop production; livestock, aquaculture and fishery statistics; food security and drought projections; nutrient balances; farming systems; land use and land-cover change; and changes in the extent and severity of land degradation and desertification. GEOSS implementation will address the continuity of critical data, such as high-resolution observation data from satellites. A truly global mapping and information service, integrating spatially explicit socio-economic data with agricultural, forest, and aquaculture data will be feasible, with applications in poverty and food monitoring, international planning, and sustainable development.”*

Increased access to satellite data will benefit both the research and applications communities. The same satellite observations that are used for agricultural monitoring can be used for a host of terrestrial scientific applications. Transitioning moderate resolution satellite observations to the

operational domain and securing free and open access to the data will greatly benefit both the science and applications communities alike.

Continuous satellite measurements, such as following the MODIS or MERIS spectroradiometers, are needed for monitoring agriculture. Long-term moderate resolution observations (i.e. Landsat class) – such as that planned with the European Space Agency’s Sentinel-2 series or with the VIIRS (Visible Infrared Imaging Radiometer Suite) – will be needed, but with an increased temporal frequency (i.e. 3 to 5-day coverage) to monitor changes in cropland and crop area and to drive crop production models and famine early warning systems. Targeted high resolution (1 to 3 m, i.e. SPOT or IRS class) imaging is also needed to monitor crop conditions in subsistence agricultural regions, to improve national agricultural production estimates, and to help monitor the agricultural aspects of carbon management. Recent advances in microwave remote sensing for agricultural monitoring also warrant further investigation.

An improvement of the kind expected from GEOSS in the mapping, monitoring and characterization of agricultural lands, their use and change will represent a tremendous progress. The science community currently engaged in studies of water quality and use, carbon and nitrogen cycling, biodiversity and sustainability will be able to access the full suite of data that they need to answer these and other scientific questions. Particularly important are the vital challenges related to the growing demands to help farmers produce more food in the face of expanding populations, shifting dietary demands, land and water shortages and climate change, and to doubling the food supply by 2050 in ways that are environmentally sustainable and help bring people out of poverty and hunger at the same time. Accurate and up-to-date global data sets on agricultural lands will be useful inputs for land use and integrated assessment modelling.

One cannot overstate the importance of increasing capacity for the international science community to participate in agricultural monitoring using earth observations. In particular, developing country scientists would benefit significantly from the increased access to earth observations and extensive training in their use afforded by GEOSS.

GEOSS will help achieve these goals, both through the establishment of a sustained and comprehensive global observing system and through the open and timely access to the data from the whole suite of observing systems associated with GEO Data Sharing Principles.

## 4.8 Ecosystems and Biodiversity

The GEOSS 10-Year Implementation Plan states that “Implementing GEOSS will unify many disparate biodiversity-observing systems and create a platform to integrate biodiversity data with other types of information. Taxonomic and spatial gaps will be filled, and the pace of information collection and dissemination will be increased”. It also adds that “Issues in [the area of Biodiversity] include the condition and extent of ecosystems, distribution and status of species, and genetic diversity in key populations. Implementing GEOSS will unify many disparate biodiversity-observing systems and create a platform to integrate biodiversity data with other types of information. Taxonomic and spatial gaps will be filled, and the pace of information collection and dissemination will be increased.” Some of the many expected science benefits of an operational GEOSS for biodiversity and ecosystems are discussed hereafter.

## **4.8.1 Land Biodiversity**

### **4.8.1.1 Pattern and change detection**

Some biodiversity changes are rapid and obvious, but most are slow and not recognised until too late. The acquisition of biodiversity-relevant information (i.e. on both biodiversity and the drivers of change, which largely come from other SBAs) on these “slow variables” is essential to the detection and understanding of a changing planet. Doing so requires a “sustained” and “harmonised” observing system, like GEOSS.

### **4.8.1.2 Evolution**

Evolutionary processes are the underlying engine of biodiversity. Many of the details of evolutionary process and history remain mysterious. The field would make more progress if reliable and comprehensive information were readily available on the distribution of species and their genetic composition. Doing so requires a globally coordinated effort at information sharing, such as is proposed by GEOSS.

### **4.8.1.3 Ecological dynamics**

We are in general still a long way from a predictive theory of ecosystem dynamics, and one of the main impediments is reliable, long-term, spatially comprehensive data regarding changes in the structure, function and composition of ecosystems. Only a globally-coordinated, long term observation programme can alleviate this constraint.

### **4.8.1.4 Functional biodiversity**

The connection between what species are present, in what proportions, and the ecosystem consequences, remains one of the great contemporary scientific challenges. A similar disjunction currently exists between genetic composition and organism function. To address the challenge requires simultaneous, co-located information on the different levels of biological organisation, from genes through organisms to ecosystems. That is precisely what GEO BON is set up to do.

## **4.8.2 Marine Biodiversity**

Systematic exploration of the oceans and studying spatial and temporal dynamics require a system of observation technologies that only starts to become reality. For the open ocean only very few stations that cover decadal time scales are operational. For coastal areas, long term time series are more frequent but they continue to be sampled in isolation and no mechanism exists that allows for standard protocols, data quality control and analysis, etc., that is needed in order for data from different sources to be combined. Moreover, there is no network that ascertains the spatial and temporal coverage required to allow for adequate detection of biodiversity changes at regional and continental scale. Moreover, most data are coming from the northern hemisphere.

The establishment of networks of biodiversity observatories which cover the world's oceans adequately will be a major challenge for the coming decade. The need to comprehensively determine and monitor marine diversity is fundamentally important to our societal needs. Past and existing efforts of global, regional and national organizations, marine institutes and

biological stations of universities as well as individual scientists have laid a strong foundation for this work. Long term time series of biodiversity data have been and are being collected by many marine institutes and stations in developed and some developing countries, mainly focusing on coastal marine environments but increasingly on the open and deep oceans as well. One example is the Census of Marine Life (CoML) with major funding for the last ten years and ca. 2,000 active scientists worldwide. ComL has given an enormous boost to a much better understanding of marine biodiversity. Biogeographic data generated by the Census are integrated, together with data from many other sources, in the Ocean Biogeographic Information System (OBIS, <http://www.iobis.org>). The Census will officially end in 2010 and has been very successful and thus may serve as a template for GEO BON as far as the marine component is concerned regarding the challenges, concepts, activities, logistics, data integration and deliverables on the short and long term of GEO BON, including the crucial involvement of regional BON's (cf. the National and Regional Implementation Committees (NRIC) of CoML), and other organizations active in certain regions or ecosystems of the oceans such as the newly established Circumpolar Biodiversity Monitoring Program (CBMP, [www.cbmp.is](http://www.cbmp.is)).

What is needed now, that GEOSS will help achieve, is to integrate the outputs from these various marine monitoring and observation efforts into a cohesive "system of systems" which will enable researchers, resource managers and policy makers to rapidly assess what is known about a particular marine region, ecosystem, species or population; to identify changes or trends at these various levels; and in those areas where appropriate models exist, to forecast future trends based upon different possible scenarios. It must be made clear that the magnitude of this task is challenging but feasible because of technological advances and the existence of a global community of scientists and institutions and the potential for global cooperation to resolve these issues.

Looking to the future, the challenges that GEOSS will help confront in the marine realm are to identify, assimilate and integrate existing data streams and to develop a worldwide system of biodiversity observatories allowing for measuring biodiversity change in its environmental context. The data obtained will reflect the broad diversity of marine life as well as the extreme complexity of marine ecosystems, from top predators like sharks and whales to the vast majority of marine organisms – the microbes which pervade the entire volume of this, the largest living space on planet earth. Data assimilation frameworks exist for some data types (e.g. genetics with GenBank, species distribution information with OBIS), but have to be developed for the many other types of data GEO BON will have to deal with (e.g. physiology, communities, interactions, habitats). Even for the established frameworks, we need mechanisms and incentives for data custodians to share these data with the wide community of users. Only when the information is available on line and satisfies criteria of coverage and quality, can it be used to document marine biodiversity and its changes, identify biodiversity hot spots and extreme environments, monitor representative habitats worldwide on decadal scales and provide information required for models and scenarios on future biodiversity that are needed to protect the oceans and at the same time allow for sustainable exploitation of marine resources.

## 5. Summary and Conclusions

The concept of GEOSS as a system of systems responds in a sense to the vision of the Earth as a system of systems. Earth sciences are data dependent. However observations as such are not enough to understand how the Earth system works and to predict its evolution. On the other hand the deployment of an adequate Earth observing system cannot be made without some a priori in-depth knowledge and understanding of the Earth system functioning.

This is why the relationship between GEO and science needs continuous attention. Science has multiple roles to play with respect to GEO:

- Science is the foundation upon which are based the initial set of applications delivering the societal benefits expected from GEOSS;
- Science provides the indispensable test bench against which GEOSS observations must be verified and validated;
- Science also provides the tools necessary to assess and control the quality of application products based on GEOSS;
- Science is needed to improve the applications in response to GEOSS user assessment of their value; and,
- Science has the potential to develop new applications in response to GEOSS users' evolving needs and requirements.

Conversely observations gathered through GEOSS will nurture Earth science, contribute to elucidating processes at work, resolve environmental issues, and more generally help advance our overall understanding of the Earth system. The constant dialogue between GEO and science is a necessary component of the strategy leading to GEOSS implementation.

The present document is aimed at contributing to this dialogue. It provides an overview of the most critical research needs in terms of research at the mid-point in the implementation of GEOSS. As such it may serve as a reference for organisations funding research and interested in providing a sound contribution to the development of GEOSS in GEO member countries as well as a tool within GEO Participating organisations to prioritise their activities. At the same time this report includes a brief review of the benefits that science and research can expect from GEOSS. Though this may seem obvious it appears that there is still a lot to be done to convince the scientific community at large to invest into GEO and devote more directed efforts towards its accomplishment in the desired timeframe. The involvement of scientists in their laboratories, universities, their sense of ownership of the system of systems under construction, are necessary if the whole GEO enterprise is to deliver its benefits to society and provide the wealth of observations with which to improve our knowledge of planet Earth and to sustain the development of mankind and the preservation of other living species.

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## 6. Glossary

<b>AWS</b>	Automatic Weather Station	<b>JECAM</b>	Joint Experiments on Crops and Agricultural Monitoring
<b>CBMP</b>	Circumpolar Biodiversity Monitoring Program	<b>MERIS</b>	Medium Resolution Imaging Spectrometer (ESA)
<b>CMA</b>	China Meteorological Agency	<b>MESOR</b>	Management and Exploitation of Solar Resource Knowledge
<b>CNES</b>	Centre National d'Études Spatiales (France)	<b>MODIS</b>	Moderate Resolution Imaging Spectroradiometer (USA)
<b>CoML</b>	Census of Marine Life	<b>NCAR</b>	National Center for Atmospheric Research (USA)
<b>CoP</b>	Community of Practice (GEO)	<b>NGO</b>	Non Governmental Organization
<b>DIVERSITAS</b>	International programme of biodiversity science, sponsored by ICSU, IUBS, SCOPE and UNESCO	<b>NOAA</b>	National Oceanic and Atmospheric Administration (USA)
<b>DNA</b>	Deoxyribonucleic Acid	<b>NRIC</b>	National and Regional Implementation Committee (CoML)
<b>ECMWF</b>	European Centre for Medium-range Weather Forecast	<b>OBIS</b>	Ocean Biogeographic Information System
<b>ENVISAT</b>	European Environmental Satellite (ESA)	<b>POGO</b>	Partnership for Ocean Global Observation
<b>EO</b>	Earth Observation	<b>RADARSAT</b>	Synthetic Aperture Radar Satellite (Canada)
<b>EPS</b>	Ensemble Prediction System	<b>SBA</b>	Societal Benefit Area
<b>ERA-40</b>	ECMWF global atmospheric Re-Analysis project (1957-2002)	<b>SCOPE</b>	Scientific Committee on Problems of the Environment
<b>ERS</b>	European Earth Remote Sensing Satellite (ESA)	<b>SCOR</b>	Scientific Committee on Oceanic Research
<b>ERTS-1</b>	Earth Resources Technology Satellite, later renamed Landsat-1 (USA)	<b>SERA</b>	Societal and Economic Research and Applications
<b>ESA</b>	European Space Agency	<b>SMOS</b>	Soil Moisture and Ocean Salinity (ESA)
<b>ESSP</b>	Earth System Science Partnership	<b>SPOT</b>	Système Pour l'Observation de la Terre (France)
<b>EWS</b>	Early Warning System	<b>STC</b>	Science and Technology Committee
<b>FAO</b>	Food and Agriculture Organization	<b>SWE</b>	Snow Water Equivalent
<b>GCOS</b>	Global Climate Observing System	<b>SWFDP</b>	Severe Weather Forecast Demonstration Projects
<b>GCW</b>	WMO Global Cryosphere Watch	<b>SWIPA</b>	Arctic Council's Snow, Water, Ice, and Permafrost of the Arctic project
<b>GCW</b>	Global Cryosphere Watch	<b>THORPEX</b>	The Observing System Research and Predictability Experiment
<b>GEO</b>	Group on Earth Observations	<b>TIGGE</b>	The THORPEX Interactive Global Grand Ensemble
<b>GEO BON</b>	GEO Biodiversity Observation Network	<b>UNESCO</b>	United Nations Educational, Scientific and Cultural Organization
<b>GEOSS</b>	Global Earth Observation System of Systems	<b>VIIRS</b>	Visible Infrared Imaging Radiometer Suite (USA)
<b>GFCS</b>	Global Framework for Climate Services	<b>WCC</b>	World Climate Conference
<b>GIFS</b>	Global Interactive Forecast System	<b>WCRP</b>	World Climate Research Programme
<b>HANPP</b>	Human Appropriation of Net Primary Production	<b>WHO</b>	World Health Organization
<b>HARON</b>	Hydrological Applications and Run-Off Network	<b>WMO</b>	World Meteorological Organization
<b>ICMR</b>	Indian Council of Medical Research	<b>YOTC</b>	Year of Tropical Convection
<b>ICSU</b>	International Council for Science		
<b>IGFA</b>	International Group of Funding Agencies for global environmental change research		
<b>IGOS</b>	International Global Observing Strategy		
<b>InSAR</b>	Interferometric Synthetic Aperture Radar		
<b>IOC</b>	Intergovernmental Oceanographic Commission (UNESCO)		
<b>IPBES</b>	Intergovernmental science-policy Platform on Biodiversity and Ecosystem Services		
<b>IPCC</b>	Intergovernmental Panel on Climate Change		
<b>IRS</b>	Indian Remote Sensing Satellite (India)		
<b>IUBS</b>	International Union of Biological Sciences		

