The Global Observing System: its impacts and future

By John J. Kelly*

Introduction

Weather and its changes have a strong influence on almost every aspect of our daily lives. Weather ultimately determines what crops we grow, how we prepare for our daily activities, if, when and how we can travel, and how we respond to ongoing or impending natural disasters. Every day, across the far reaches of the globe, Members of the World Meteorological Organization provide vital services to help their constituents cope with weather-, climate- and water-related occurrences. The ability of Members to provide these vital services is in large part due to the information and observations provided by WMO’s World Weather Watch (WWW), comprising the Global Observing System (GOS), the Global Telecommunication System (GTS) and the Global Data Processing and Forecast System (GDPFS).

The GOS is complex by its very nature and requires international cooperation at the highest levels. The heart of the GOS is a surface-based subsystem that is operated mainly by Members’ National Meteorological and Hydrological Services (NMHSs) and a space-based subsystem that is operated by either national or international space agencies. An NMHS-operated Global Telecommunication System facilitates the transfer of GOS observations for a myriad of purposes that range in scale from nowcasting to climate and focus on a number of diverse but cross-cutting areas such as tropical storms, disaster mitigation, water resources, airport terminal weather and agriculture.

This article will address the importance of the WWW GOS in “taking the pulse of the planet” by providing for improved monitoring of the Earth’s atmosphere, land and water bodies—essential elements of the Global Earth Observation System of Systems (GEOSS). The GOS is complemented by another WMO-supported effort, the Global Ocean Observing System (GOOS). GOOS is the framework for coordinated and sustained international observations of the ocean and provides the primary ocean contribution to GEOSS. Strong cooperation will be required between WMO and the United Nations Educational, Scientific and Cultural Organization (UNESCO) Intergovernmental Oceanographic Commission (IOC) through the Joint Commission for Oceanography and Marine Meteorology (JCOMM) and the Intergovernmental IOC-WMO-UNEP (United Nations Environment Programme) Committee for GOOS.

WWW GOS history

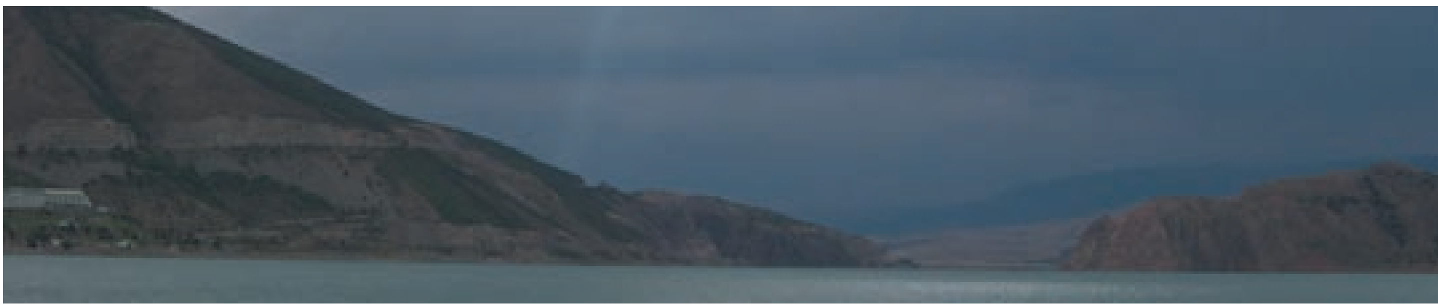
The WWW provides the basis for NMHSs around the world to coordinate the collection of oceanic and atmospheric observations, communicate these data to each other in near-real-time, develop effective tools to use the data for society’s benefit, and provide archive repositories for the data.

Since the beginning of the WWW in 1963, the GOS has provided continuous and reliable global observations for use by WMO Members. Early observational requirements of the GOS were focused mainly on synoptic meteorology and directed at the rapid expansion in civil aviation. Yet, the GOS remains dynamic and the requirements imposed upon it have continued to evolve, reflecting both innovations in observing systems and societal needs.

NMHSs have borne this through better designed and integrated observation systems, improved data telecommunications, and modern high-end computers to manage data flow and produce numerically based weather and climate products. These efforts have also led to data exchange and quality-control arrangements among NMHSs to ensure accessible and accurate data, regardless of their origin.

Over time, the data richness available from the GOS has provided the global observations needed to produce consistent weather forecasts out to seven days and to predict hazardous weather events days in advance. These

* Deputy Under Secretary, US National Oceanic and Atmospheric Administration, and Permanent Representative of the USA with WMO



The Global Observing System

predictions are now used routinely by the aviation, marine, fire weather and many other communities. Those improvements have occurred across a diverse number of application areas and have resulted in turn in increasingly positive impacts on products and services provided by NMHSs worldwide.

The evolution of the GOS was made possible by the advances in technology that have affected almost every aspect of day-to-day life on this planet. With respect to the GOS, technology has driven dramatic improvements in both terrestrial and ocean-based observing systems.

These include atmospheric soundings from more accurate rawinsondes with Global Positioning System capability, shipboard sonde systems and instrumented commercial aircraft through the Aircraft Meteorological Data Relay (AMDAR) programme. These all improve the collection of upper-level wind measurements.

Automatic weather stations deployed in remote areas operate with improved reliability under extreme conditions; advanced digital Doppler radar systems provide integrated *in situ* wind and precipitation measurements.

Technologically advanced ocean and ice buoys provide measurements of the marine and oceanic ice boundary layer environment; an array of free-drifting floats in every ocean provides information about the global heat balance; and a moored array of buoys in the tropical Pacific Ocean affords insight on the El Niño-Southern Oscillation phenomenon (Tropical Ocean-Global Atmosphere (TOGA) Tropical Atmosphere-Ocean (TAO) array).

Advances in the space-based component have been equally impressive. Instrumentation has developed well beyond the era of uncalibrated vidicon camera systems used on the early US Television Infrared Observation Satellite (TIROS). They now include passive visible, infra-red and microwave imaging systems for inferring atmosphere, cloud, land and sea- surface properties; passive infra-red and microwave atmospheric sounding systems for the determination of vertical temperature and moisture profile; and active microwave instruments for measuring rainfall, sea-level altimetry and sea state.

The early success of the US meteorological space ventures to polar and geostationary orbit were followed by the development of similar systems by other nations, resulting in a robust space-based GOS. Today, polar-orbiting systems are operated by China, the Russian Federation, and the USA and geostationary systems are operated by China, Europe, India, Japan and the USA. Europe has plans to enter the polar-orbiting satellite arena and the Republic of Korea and the Russian Federation plan to provide operational services for WMO Members from geostationary orbit.

All operational polar and geostationary systems provide multi-channel digital imagery. Additionally, the US polar system provides microwave imaging and sounding data, and both its polar and geostationary systems provide infra-red sounding data. Furthermore, today’s space-based component of the GOS is composed of a robust operational component that is supplemented by a dynamic research component, with research satellites providing high-resolution, multispectral imagery and hyperspectral sounding data for use by WMO Members, as well as enabling derivation of tropical rainfall, ocean-surface winds, and altimetry.

GOS evolution—the way ahead

Growth of the GOS is expected to continue at an astounding rate. Major improvements are expected for the accuracy and timeliness from both *in situ* and remotely sensed data platforms. Furthermore, the volume of data associated with the newer GOS, especially those related to satellite and radar systems, is expected to increase exponentially over the next decade. A key aspect of realizing the benefits of all of these data for analysis and predictions of environmental conditions will be the development and implementation of sophisticated data assimilation systems. The data-assimilation step is crucial to maximizing the strengths of each observing system while minimizing its weaknesses in order to improve the analysis, initial conditions and subsequent forecasts for weather, water and climate, especially for extreme events.

Implementation Plan for Evolution of the GOS

Recommendations (20) for the space-based subsystem addressed: calibration, multispectral imaging (tens of channels) and hyperspectral sounding (thousands of channels), ocean surface wind and altimetry, temporal coverage for low Earth orbiting satellites, atmospheric wind and aerosol profiles from active sensors, global measurements of precipitation using active radar and passive microwave sensors and radio occultation sounders.

Recommendations (27) for the ground-based subsystem addressed: data coverage, distribution and coding, broader use of ground based and *in situ* observations, moving towards operational use of targeted observations, optimization of rawinsonde distribution and launches, development of the AMDAR programme and alternative AMDAR systems, atmospheric moisture measurements, improved observations in ocean areas, improved observations over tropical areas and new observing technologies.

At the direction of World Meteorological Congress, WMO’s Commission for Basic Systems (CBS) studied the evolution of the GOS and issued WMO/TD No. 1267: Implementation Plan for Evolution of Space and Surface-Based Sub-Systems of the GOS. One of the main purposes of the plan was to help Members prepare for the massive changes in the GOS that were anticipated over the next two decades. Forty-seven recommendations in the plan provided the framework for the evolution of the GOS (see box above).

The developers of the plan recognized its evolutionary nature and, as a result, provided comments on most of the recommendations, progress if the associated activity was already underway, actions that reflected what was to occur next, and schedules for the realization of the recommendation. CBS is reporting back to Members on a regular basis on the status of implementation recommended in this plan.

One main purpose of the plan was to help Members prepare for the anticipated massive changes in the GOS. In that document, three issues are brought forward that must be addressed for successful implementation of an evolved GOS. They deal with continuity, utilization and cooperation:

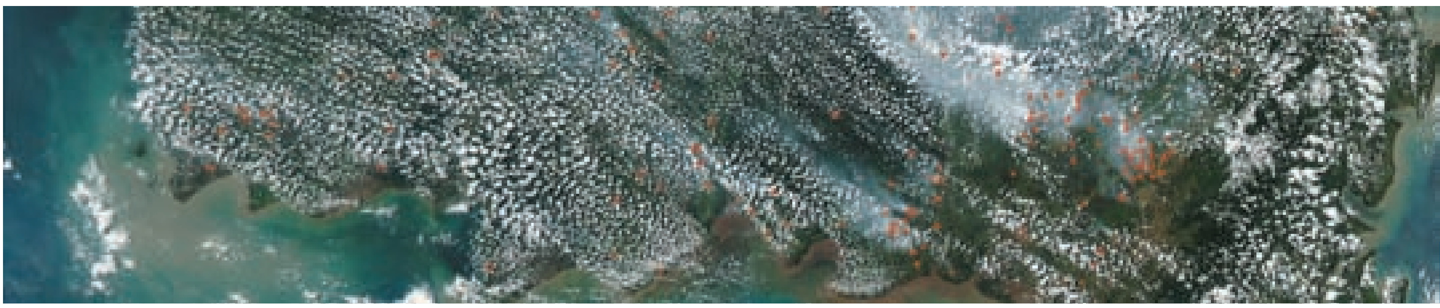
- The future GOS should build upon existing subsystems, both surface- and space-based, and capitalize on existing and new observing technologies not presently incorporated or fully exploited; each incremental addition to the GOS will be reflected in better data, products and services from the NMHSs;

- The scope of the changes to the GOS over the coming decades will be so massive that revolutionary approaches to science, data handling, data access, product development, training and utilization will be required. There is an urgent need to study comprehensive strategies for anticipating and evaluating changes to the GOS.

The implementation of the new GOS should facilitate the strengthening of cooperation at national, regional and global levels among Members. The evolution of the GOS in developing countries must address some of the issues that fall into three categories: infrastructure; training; and equipment and consumables.

The evolution of the GOS will be greatly aided by The Observing System Research and Predictability Experiment (THORPEX). New technologies and adaptive observing strategies and data assimilation will be tested and guidelines for their utilization within the GOS for weather forecasts on a one- to two-week timeframe will be developed. Other studies will deal with the exploitation of the new data and information from the GOS being exploited for nowcasting and seasonal-to-interannual and longer-term climate studies.

Studies such as those envisioned by THORPEX require a stable baseline observing system against which their results can be measured. In the development of the vision for the GOS by 2015, the space-based subsystem was based on well-defined plans by the operational and research space agencies. Thus, for the space-based subsystem, we expect, as a baseline, an improved stable operational analysis and prediction system,



complemented by a known dynamic research component. This will be focused on key observing issues and related data-assimilation advances required to take full advantage of improved observations and associated strategies, especially those related to targeted observations.

Other high-priority GOOS observation systems and capabilities that contribute to GOS are:

- Tsunami warning capabilities in the Pacific and Atlantic Oceans and the Caribbean sea as part of an International Tsunami Warning System (http://www.prh.noaa.gov/ itic/);
- Global Sea Level Observation System (http://www.pol.ac.uk/ psmsl/ programmes/gloss.info. html); and
- Global Ocean Data Assimilation Experiment (www.uwgodae.org).

Thus, we can see that the 21st century will be filled with opportunity and challenge. The intersection of the technological advances referred to earlier with advances in communication capabilities provides an unprecedented opportunity to capitalize on the phenomenal growth in data and information that will become available during the first 25 years of this century.

Particularly relevant is the evolution of the WMO Information System (WIS) and how it will allow for the provision of data and information and its use within a wide array of model-based prediction systems to Members on scales appropriate to their needs.

Data and models

Numerical weather prediction relies on measurements of temperature (and/or pressure), winds and moisture. There is no single observing system that can provide all three parameters at the same place and time with the required accuracy. Also, there is no single observing system that provides a uniform (in space and time) distribution of these measurements. Both ground- and space-based components of the GOS present a major challenge to derive data-assimilation and modelling systems which account for the strengths of each observing system, while avoiding their weaknesses.

For example, the data assimilation should be able to take into account the poor vertical but good horizontal resolution and spatial distribution of satellite data, while also accounting for the good vertical but poor horizontal and temporal resolution of radiosonde data. Likewise, the system should also be able to account for the good temporal resolution but poor spatial distribution of aircraft data. It is through sophisticated assimilation systems and models that a coherent depiction of the Earth's atmosphere from the measurements achieved by the GOS will hopefully be derived.

Over the next decade, with advanced satellite systems, ground-based radar, AMDAR and other *in situ* systems, there will be over a million times more data available. Most of those data will be focused on global NWP through complex data-assimilation systems. These are an inherent component of the entire prediction system. While it is highly unlikely that any NMHS will want all the data all the time, all NMHSs will want some of the data all the time and parts of the data some of the time. While models appear to be entering an era of targeted observations, for NMHSs there can be no doubt that a targeted information era has begun.

Up to five years ago, it was not possible to realistically address this issue. Today, however, the symbiotic relationship that is developing between technology and communications is making it a reality. Thus, data that flow through the WIS will be made up of a stable operational component complemented by a dynamic segment that depends on user needs, model capabilities and advances in data assimilation. Defining how those two components coexist will require development work that addresses societal needs, NMHS capability, WIS components and the symbiotic relationship between technology and communications.

Requirements for the surface-based subsystem to become a viable baseline

- A complete and stable Regional Basic Climate Network (RBCN) embedded within a Regional Basic Synoptic Network (RBSN). Some components may be operated in a flexible manner
- Improvements in AMDAR and Troposphere Airborne Meteorological Data Reports (TAMDAR)
- Increased oceanic coverage to include upper-air soundings, drifting buoys and Argo floats. This would provide a stable baseline against which new observing technologies and strategies could be tested. Argo, drifting buoys and other oceanic observations are also critical elements of GOOS.

As the requirements from Members for user services is growing, it is not unreasonable to expect Member needs from the GOS to expand. In the past, global NWP requirements for data were based on communications and computer technology that were applicable to the mid- to late 20th century. Today, modern Global Data Processing Centres (GDPCs) are using exceptionally powerful computers with advanced data-assimilation models which couple asynoptic data into models with advanced physics.

Both Observing System Experiments (OSEs) and Observing System Simulation Experiments (OSSEs) have clearly shown that continuous assimilation of high-resolution data into those models results in improved global forecasts. During the past decade, this has changed so that, to provide the best forecasts, today's modern GDPCs now require all data from upper-air observations—not just significant level data—as well as hourly surface data and data from special networks. This need lies beyond the current scope of Resolution 40 (see box on page 199) but, clearly, any Member that is truly interested in accurate global forecasts must respond to that need. An innovative outlook means: trust across borders, nation to nation, level of government to level of government, and government to citizen. An innovative outlook means that the user becomes integrated as a part of the system at all levels. To avail ourselves of that opportunity will require Members to work together in global science and operational partnerships.

Distribution of increased amounts and types of data for WMO and related programmes is under development in the Future WMO Information System ((FWIS): http://www.wmo.ch/web/www/FWIS-Web/homefwis.html). FWIS will build on the current Global Telecommunication System that distributes data among processing centres.

Staffing and training

Some fear that the role of the human being will decrease with this revolution in technology. Nothing could be further from the truth. Some activities will be replaced through better uses of technology. However, the increase in data volume, products and applications areas and our ability to monitor and forecast on a global scale will place the human being at the very centre of how that information is used optimally on a daily basis in a tremendous number of areas.

Anticipating the weather of the next week will allow for applications to focus on the mitigation of natural disasters by concentrating on regions prone to flooding, for example, and then managing the information and data flow into the NMHS that will allow for the impacts of the phenomena to be addressed in an efficient and timely manner. Thus, training an increasingly diverse user community in how to utilize the system and to access the correct data for a specific application will be of paramount importance.

Furthermore, training in advanced applications of satellite data and their use in nowcasts and numerical prediction systems will take on increasing importance. Satellite data will provide information for a variety of real-time applications ranging from nowcasting severe weather and floods to the detection and monitoring of areas of snowmelt, wet ground, fires, aerosols, surface temperature for heat stress and forecast model output fields. With the massive increase in information and data that will become available over the next decade, it is necessary for WMO to embrace even more training opportunities, especially in relation to developing and implementing more

The evolution of the GOS will be greatly aided by The Observing System Research and Predictability Experiment (THORPEX). New technologies and adaptive observing strategies and data assimilation will be tested and guidelines for their utilization within the GOS for weather forecasts on a one- to two-week timeframe will be developed.

sophisticated data- assimilation system designs with the future GOS in mind.

Strong ties to GEOSS

The phenomenal increase in capability that is expected to occur within the GOS places it on a natural intersection with GEOSS. Indeed, there is a clear juxtaposition between GOS and GEOSS. In June 2004, the 56th session of the WMO Executive Council formally declared that several WMO systems, including GOS and WIS, should be considered as core components of GEOSS. Furthermore, in the long view, the GOS, in some ways, cross-cuts each of the GEOSS nine societal benefit areas, some quite substantially:

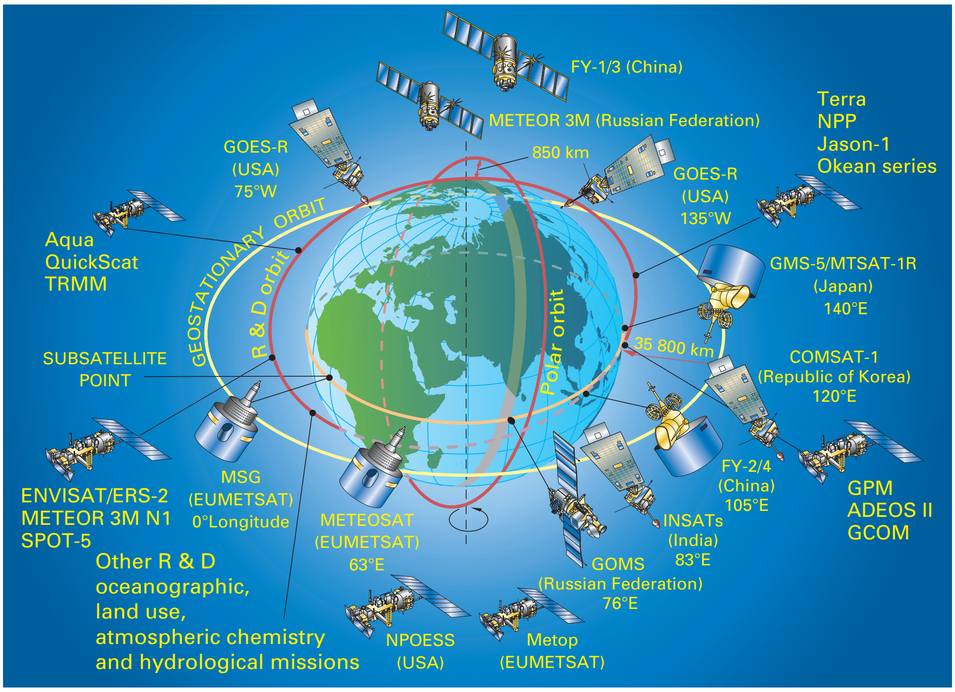
- Improving weather information, forecasting and warning;
- Reducing loss of life and property from natural and human-induced disasters;
- Improving water-resource management through better understanding of the water cycle;
- Understanding, assessing, predicting, mitigating and adapting to climate variability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

WMO is an important contributor to GEOSS and is home to the Secretariat of the intergovernmental Group on Earth Observations (GEO) at its Headquarters in Geneva . WMO is also an important contributor to GOOS. GOOS is composed of global ocean and coastal ocean components and has several submodules: the Global Climate Observing System (GCOS), Living Marine Resources Panel, Health of the Oceans, and the Global Terrestrial Observing System. In fact the GCOS programme, of which WMO is a prime sponsor, has been recognized as the formal climate component of GEOSS; the GCOS Implementation Plan, which can be found at http://www.wmo.int/web/gcos/gcoshome.html, is part of the overall GEOSS implementation effort.

The space- and ground-based components of the WWW are among the core contributors to GEOSS. Observing and accurately predicting the Earth's environment is critical for the health, safety and prosperity of all nations. As the responsibilities of WMO Members increase to embrace broader roles in monitoring and forecasting for the environment, many of the subsystems that contribute to GEOSS that are not part of the WWW will become important for WMO Members.

Too often, we become enthralled with placing an economic value on the need to justify monitoring climate, weather and the Earth's environment as well as our ability to forecast them. As is clearly recognized by the GEOSS 10-Year Implementation Plan:

Understanding the Earth system—its weather, climate, oceans, land, geography, natural resources, and natural and human-induced hazards—is crucial to enhancing human health, safety and welfare, alleviating human suffering (including poverty), protecting the global environment and achieving sustainable development.



The space-based component of the GOS

The reason we want to monitor the "pulse of our planet" is not solely for economic benefit but for human health and well-being, while learning how to sustain humankind's future on our evolving planet Earth.

The future of the GOS and NMHSs

There is no question but that we are improving our ability to utilize data from the GOS. The reason clearly lies in more and better observations and our ability to utilize them. Today, we have improved high-resolution models with better physics that are linked to improved observations with powerful data-assimilation systems. As the GOS evolves, continued progress in science, models and data assimilation, coupled with awareness of the importance of transitions, will help guide us toward full utilization. As we move forward, there are some critical issues that will accompany the implementation of the evolving GOS:

- The broad implications of targeted observations need to be addressed, with guidance on targeting needing to be developed only after careful scientific consideration;
- How adaptive observing is implemented within the GOS needs full consideration. Observations not deemed necessary at a particular time in one part of the world may provide valuable information elsewhere;
- How Members can best benefit from the tremendous amounts of data that will become available;
- How we train Members to fully utilize data from the GOS so that opportunities are not lost;

Resolution 40

Twelfth World Meteorological Congress adopted Resolution 40 (Cg-XII)—WMO policy and practice for the exchange of meteorological and related data and products, including guidelines on relationships in commercial meteorological activities.

The adoption of this resolution 10 years ago was a landmark in the history of WMO, ensuring that its Members would be able to exchange data and products free of charge and without conditions on their use.

Well known simply as Resolution 40, it was followed four years later by a similar resolution covering hydrological data (Resolution 25 (Cg-XII).

- While not all Members will have the ability to cope with the full datasets, all Members will have a responsibility to contribute fully to the evolving GOS; this may require refinements to data-exchange policy.

Applications areas are expanding dramatically with an unparallelled opportunity for growth. For almost any given applications area, opportunities to exploit multiple datasets from a variety of sensors, all with different characteristics, will abound. Data volumes will be tremendous in comparison with today's operational systems—at least six times greater.

We should expect great improvements to the GOS, including very high spatial and temporal resolution with both space- and ground-based active and passive sensors. In concert with these new capabilities, we must prepare for vast growth in data volume and content which will be available from systems in the first few decades of the new century. On the horizon lies the promise of improved data for the various services Members provide. Better science will occur by realizing the opportunities afforded by the future GOS through new approaches, international partnerships and science teams.

Planning for tomorrow's GOS must take into account all observing assets, capitalizing on their strengths as key components of a comprehensive and sustained GEOSS. As we take advantage of the future's promise, marked changes will occur in the ways we approach data handling, science, product development, training and utilization. To prepare for the daunting task of monitoring and understanding the Earth system from these new data and ensuring their full utilization, we must work together in global science and operational partnerships.

We move forward by building on the successes of today and planning and developing appropriate mechanisms focused on exploitation as a global community in partnership: the user, national and international science groups, operational agencies, research satellite agencies and WMO. This is a challenge but one which must be met.

We strive for full exploitation, but whose responsibility is it to ensure that the future GOS is utilized to maximize benefit in a given applications area: the user, national and international science groups, the operational agencies, the research agencies, WMO? In fact, the responsibility rests with all communities. In this regard, GOS, as a major contributor to GEOSS, will provide a wider spectrum of users and further increase the value of its observations.