GROUP ON
EARTH OBSERVATIONS

Our ref.:2014-41/GEO/WSR
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GEO Principal

Geneva, 24 February 2014

Dear GEO Principal,

Please allow me to draw your attention to the attached Executive Summary of the recently completed Global Earth Observation System of Systems (GEOSS) Water Strategy Report (WSR). The WSR was developed by the Integrated Global Water Cycle Observation (IGWCO) Community of Practice during the past one and a half years, and contains a review of the current monitoring status for components of the water cycle, culminating with a number of recommendations to address gaps and requirements. A hard copy of the Executive Summary is being sent to you by post.

Over the next 12 months, a GEOSS Water Implementation Plan (WIP) will be developed to respond to the WSR. The plan will consolidate the commitments of the Group on Earth Observations (GEO), its Members governments, and Participating Organizations to begin building a global water monitoring system. In addition, the WIP will influence the development of water related targets in the new GEOSS to 2025 Implementation Plan and the associated work plans.

In order to develop the WIP, the following steps are anticipated:

1) The information and recommendations in the GEOSS WSR will be publicized and disseminated throughout the full GEO Community;

2) The Committee on Earth Observation Satellites (CEOS), Future Earth, the World Meteorological Organization (WMO), and other agencies and initiatives will be invited to identify those recommendations they would be interested in helping address;

3) GEO Members and Participating Organizations (POs) will be invited to comment on the WIP recommendations and identify potential contributions, in the form of either current or planned activities or projects, to address the recommendations;

4) Proposed GEO Member and PO activities/projects will be compiled by mid May, and an initial draft WIP prepared and circulated by the end of August 2014; and

5) The WIP, including actions, deliverables, and milestones, along with a tracking system for measuring progress, will be completed by the close of 2014.

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At the end of May 2014, the IGWCO Community of Practice will hold its annual meeting in Tokyo, during which initial preparations for the WIP will be discussed. I therefore invite you to consider what activities/projects your government or organization may wish to contribute in addressing the recommendations contained in the GEOSS WSR, and submit your proposals to IGWCO Chairman Mr Richard Lawford (richard.lawford@morgan.edu), with Douglas Cripe (dcripe@geosec.org) at the GEO Secretariat in copy.

Thank you for your support of this important initiative.

Yours sincerely,

Barbara J. Ryan
Director, GEO Secretariat

GROUP ON EARTH OBSERVATIONS

EXECUTIVE SUMMARY

THE GEOSS WATER STRATEGY FROM OBSERVATIONS TO DECISIONS

The GEOSS Water Strategy: From Observations to Decisions

Executive Summary

This Executive Summary is a companion to the GEOSS Water Strategy Report, both of which have been prepared for the 2014 GEO Summit in Geneva, Switzerland. It consists of a synthesis of the highlights from the much more comprehensive GEOSS Water Strategy Report and a listing of the recommendations put forward in that Report. GEO Members and Participating Organizations are encouraged to review the Report, discuss specific aspects with the authors and the GEO Water Task Points of Contact (see Appendix A), and to help the water community to address the recommendations that are listed in this Summary, particularly as they apply to their countries and to the overall goals of GEOSS and water security. The Report is a community effort that attempts to present a balanced view of the status of Earth observations applications in the water sector from all parts of the globe. Chapter and section authors are listed along with other contributors in Appendices B and C, respectively.

Editor: Richard Lawford
Technical Editor: Andrée-Anne Boisvert

Publisher: Japan Aerospace Exploration Agency

Cover design: Tétro Design (Funded by NASA)
Printed in Japan by JAXA and I and A Corporation.

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Table of Contents

The GEOSS Water Strategy: From Observations to Decisions

Executive Summary

Message from the Executive Director

The Group on Earth Observations (GEO) is a voluntary partnership of governments and international organizations that is coordinating efforts to build a Global Earth Observation System of Systems (GEOSS). Launched in response to calls for action by the 2002 World Summit on Sustainable Development and by the G8 (Group of Eight), GEO now includes 89 governments, the European Commission, and 67 partner organizations. Through GEOSS, GEO provides a framework within which these partners can develop new projects and coordinate their strategies and investments.

GEOSS will provide decision-support tools to a wide variety of users. GEOSS addresses the needs of the water community through its Water Societal Benefit Area. The "system of systems" will proactively link together existing and planned water cycle observing systems around the world and support the development of new systems where gaps currently exist. It will promote common technical standards for information-gathering and exchange to facilitate the development of coherent datasets. The GEOPortal provides a single Internet access point for users seeking water data, imagery, and analytical software packages relevant to all parts of the globe.

Led by the Integrated Global Water Cycle Observations Community of Practice and supported by the Committee for Earth Observation Satellites, the water community has developed a GEOSS Water Strategy Report that gives direction to GEOSS water systems and activities for the next decade. This Executive Summary provides the highlights of the full report and tables a number of recommendations that GEO will need to consider over the next months and years. I welcome this Executive Summary and look forward to working with all GEO Members to address these recommendations and to strengthen the water component of GEOSS.

Barbara Ryan
Executive Director
Group on Earth Observations

The full GEOSS Water Strategy Report will be available through www.earthobservations.org.

The GEOSS Water Strategy: From Observations to Decisions

Executive Summary

Introduction and Background

The availability of quality water continues to be a major issue for the Earth system and humans in particular. Water is essential for ensuring food and energy security, for facilitating poverty reduction and human health, and for the maintenance of ecosystems and biodiversity. There is a growing concern that the water available in many regions of the world will not be sufficient to meet emerging demands arising from population growth, industrial expansion, and climate change.

As readers are aware, the Group on Earth Observations (GEO) is coordinating the development of the Global Earth Observation System of Systems (GEOSS), a global, coordinated, comprehensive, and sustained Earth observing system. Water is one of the nine Societal Benefit Areas (SBA) being developed within this framework. Activities within this Societal Benefit Area are coordinated primarily by the Integrated Global Water Cycle Observations (IGWCO) Community of Practice (CoP). The GEOSS Water Strategy Report outlines a series of interrelated decisions and actions for using Earth observations to support improved decision-making to ensure the long-term viability of water resources and to enable the integrated management of water resources at the national, basin, and global scales. The Report is intended for GEO members (nations and organizations) that are committed to contributing to addressing the world's water problems by building a stronger water activity within GEO. The Report addresses the needs of water managers who seek information using modernized information management systems. It is relevant to GEO stakeholders, including researchers who need to understand priorities for knowledge and new technologies; to investors and aid organizations that need to plan strategies to effectively invest in future water infrastructure; and to the end-users who want to secure their access to safe water. In order to deal with these needs and to facilitate the use of Earth observations in water management, the GEOSS Water Strategy has adopted the following objectives:

1) Provide a framework for guiding decisions regarding priorities and strategies for the maintenance and enhancement of water cycle observations,
2) Enable improved water management based on a better quantification of fluxes and stores in the global water cycle, eventually leading to an ability to close the water budget,
3) Promote strategies that will facilitate the acquisition, processing, and distribution of data products needed for effective management of the world's water resources,
4) Provide expertise, information systems, and datasets to the global, regional, and national water communities through support to UN Water and its agencies (e.g., World Meteorological Oragnization) and programmes, and other international science and applications programmes, and
5) Increase availability and use of data, information, and indicators of the quality of inland and near-coastal waters to support an operational water quality decision-making system.

Although many plans exist for global water issues, the GEOSS Water Strategy is unique by virtue of its focus on Earth observations and its compatibility with the GEOSS framework. GEOSS facilitates the integration of water-related issues with other GEO Societal Benefit Areas (see Table 1). GEO promotes open access and the distribution of data at minimum cost and coordinates the development of tools and infrastructure. Within the limits of a volunteer "best efforts" programme, GEO helps to bring the principles of good governance to water management. Working within the GEOSS framework, this Water Strategy directs water-related Earth observations to address:

1) The security of domestic and useable water supplies in all areas of the world,
2) The adaptation of water resource systems to the impacts of climate change,
3) The water-related health and welfare needs of the poor in developing countries by ensuring better access to water information,
4) Extremes, including floods and droughts, and their effects on plans for infrastructure protection and secure water supplies,
5) The information needs of the nexus of water, energy, and food issues as they relate to water security and sustainable development (the Water-Energy-Food Security Nexus), and
6) Access to water for ecosystems and biological systems.

Table 1. Linkages between the Water Societal Benefit Area and other GEO SBAs and themes. Note: (a), (b), and (c) are GEO themes.

Societal Benefit Area	Links with Water Information
Agriculture	Drought monitoring, Irrigation planning, Water-Energy-Food Nexus, Soil moisture, Fertilizers, Water quality
Biodiversity	Water stress and impacts in biota, Water infrastructure and biodiversity, Wetlands mapping
Climate	Evapotranspiration, Precipitation, Soil moisture, Drought, Adaptation to climate change
Disasters	Floods, Droughts, Groundwater
Ecosystems	Water and ecosystem services, Aquatic habitat in drought conditions, Wetlands mapping, Flood and drought impacts
Energy	Hydropower, Cooling water, Geothermal, Biofuels
Health	Water quality, Precipitation, Surface water store, Availability of potable water, Effects of flood cycles
Land Management (a)	Runoff, Erosion, Sediment production, Infiltration
Oceans (b)	Coastal runoff, Near-shore water quality
Socio-Economic (c)	Water use, Role of water in trade, Urban water issues
Water	Water availability, Snowpack, Streamflow, Surface water store, Water withdrawals, Water infrastructure planning
Weather	Precipitation, Soil moisture, Flood monitoring and prediction

Engaging users in providing insights about their water information needs and testing new Earth observation products is a major challenge. The results of a recent GEO survey of user needs for water data (see http://sbageotask.larc.nasa.gov/Water_US0901a-FINAL.pdf) provides a starting point for defining user needs. This Strategy also recognizes the importance of engaging users in regular reviews of their needs and new products. Increasingly, governments fund programmes based on public commitment to an application or service; consequently, building user loyalty is important for the sustainability of observational programmes. Public investment in the collection of new data types and the use of those data to develop new products outstrips the investment in developing structured user engagement. Options for a more structured approach between the providers of new Earth observation data products and those who will benefit from them are explored in this Report. For example, this Strategy promotes the development of Essential Water Variables, which will designate variables as essential if they are critical for water management decisions and also serve as indicators of environmental change. Assessments of the benefits of the full implementation of Earth observations in decision-making must consider that decisions often span many time scales as they extend from long-term planning to short-term operational decisions and accrue benefits over multiple time scales. As part of these options, this Report also begins to explore ways whereby the GEO Water enterprise can move toward implementation models based on business paradigms.

Satellite and in-situ data have different strengths that must be harmonized in a comprehensive observing and information system. GEO Water activities rely on three coordinating mechanisms for observations. The Committee on Earth Observing Satellites (CEOS) plans multinational initiatives and coordinates the measurement programme services of the major space agencies, including operational agencies (e.g., EUMETSAT, JMA, NOAA) and research agencies (e.g., ESA, JAXA, NASA). The World Meteorological Organization (WMO) has taken the lead for weather, water, and climate variables and, through the Global Terrestrial Network for Hydrology, has set up a coordination mechanism for observational networks and data centres archiving in-situ water cycle data. The WMO also manages the Coordination Group for Meteorological Satellites, which provides an international forum for the exchange of technical information on geostationary and polar-orbiting meteorological satellite systems as well as the management of the International Precipitation Working Group. Within WMO, the World Climate Research Programme (WCRP), through its Global Energy and Water Exchanges (GEWEX) project, leads many of the research aspects of this programme. This Strategy calls for strengthening the coordination and management of in-situ networks, particularly those involving hydrologic measurements, since it is expected to be a number of years before space-based observation capabilities exist to measure river discharge operationally.

Priority Water Variables

In terms of planning strategies for specific variables, the needs of two primary client groups must be recognized for these data types: water cycle variables related to climate and macroscale hydrology, and water variables that are essential for applications and operations involving water resources management.

Measurements of **water vapour and clouds** are important for accurate precipitation forecasts, for estimating surface energy budgets, and for assessing the climate feedback effects that amplify or otherwise offset the climate change signal. In global climate models, a modest error in predicted cloud cover could change the sign of the global warming signal. Data are needed on the horizontal and vertical distributions of clouds, their scaling properties, and cloud microphysical properties.

Humidity measurements are important, especially in the lower troposphere, where space-based measurement systems have difficulty penetrating. While ground-based Raman lidar or Differential Absorption Lidar can meet the requirements, space-borne lidar is unable to measure water vapour under warm clouds. Column water vapour values retrieved from Global Positioning Systems (GPS) do provide useful information. Satellites have enabled the development of two-dimensional cloud distributions using space-borne visible and infrared radiometers. However, vertical distributions of clouds and in-cloud droplet distributions are important parameters that are not presently well-measured. Space-borne Mie lidar, a cloud radar (W-band radar) on the CloudSat satellite, and similar instrumentation on the EarthCARE mission (expected in 2016), will address this need. Vertical profiles of latent heating have been made possible by the emergence of active sounding sensors that can probe the vertical structure of the cloudy atmosphere.

Precipitation is a primary input to the hydrological cycle. Precipitation measurements are crucial to understanding and predicting the Earth's climate, weather, streamflow, soil moisture, and water availability. Anomalies in the frequency and intensity of precipitation (see Fig. 1) result in floods and droughts. Methods for measuring precipitation include: gauges that measure the precipitation arriving at the surface, surface- and satellite-based precipitation radars, observations of passive microwave radiance from Low Earth Orbit (LEO) satellites, and infrared radiance observations of clouds from both LEO and Geostationary Earth Orbit satellites that enable retrievals of precipitation in the atmosphere. The most precise space-based observing system is the precipitation radar (PR) on the joint NASA/JAXA Tropical Rainfall Measuring Mission (TRMM) satellite. Although there is a limitation in the spatial

Figure 1. Accurate measurements of rainfall are needed to estimate water availability. Variations within this rainshaft illustrate the small-scale fluctuations in precipitation that make detailed knowledge of the water cycle very challenging. (Source: University Corporation for Atmospheric Research Digital Image Library, http://www.fin.ucar.edu/res/sites/imagelibrary.)

and temporal coverage of the PR, the upcoming National Aeronautics and Space Administration (NASA)/Japan Aerospace Exploration Agency (JAXA) Global Precipitation Measurement (GPM) Mission will provide unprecedented precipitation observations and will help to remedy these limitations. Future systems for precipitation monitoring are likely to rely on satellite-based radars that can actively and remotely sense the precipitation field.

Data from each of the satellites and satellite series serve as the basis for regional and global precipitation datasets. Over the past two decades, a number of algorithms have been developed and used to routinely produce data products based on combinations of microwave, infrared, and gauge data to provide high-resolution precipitation products.

Evaporation and Evapotranspiration (ET) represent the moisture fluxes from the underlying ocean or land surface to the atmosphere. Land-based ET reflects the rate of plant growth and drying of the surface. ET measurements can be used to estimate consumptive water loss, especially irrigation losses and non-productive evaporative losses. Accurate flux values at a particular location can be derived from in-situ measurements (land) and sea surface temperature estimates (ocean evaporation). Land-based in-situ ET measurements are generally provided by Bowen ratio, eddy covariance, scintillometer, and remote sensing methods as well as lysimetric and soil water balance methods. Estimating ET and closing the water balance for the continental and global scales remains challenging. Within this Report, evaporation and ET are recognized as Essential Water Variables and are progressing toward recognition as Essential Climate Variables as well. Measurement networks like FLUXNET need improved standards for processing and archiving their data. Although satellites provide measurements from which ET estimates can be derived, higher-resolution thermal imagery is needed to provide better estimates for agricultural and other applications.

Soil moisture is important for climate and water resources management. In particular, soil moisture regulates the partitioning of incoming radiative energy into sensible and latent heat fluxes, making it relevant to the climate community. It also partitions precipitation between infiltration, runoff, and evaporation, making it equally important for the water resources community. While some national and regional in-situ soil moisture networks exist (e.g., Australia, China, France, Russia, U.S.) for agricultural and research purposes, a global network has yet to emerge. The lack of funding, combined with the absence of a widespread demand for a global network, and the wide diversity of instruments, procedures, and standards for in-situ soil moisture measurements, has slowed its development. Both active and passive microwave systems have been used to estimate soil moisture, with skill coming through the use of measurements in the low microwave spectrum (1-10 GHz), which are sensitive to soil moisture and vegetation dynamics.

Currently, the European Space Agency's (ESA) Soil Moisture and Ocean Salinity mission provides operational soil moisture products at a 15-km resolution and repeat coverage of one to three days. Other sources of passive soil moisture are the WindSat instrument on the U.S. Navy's Coriolis satellite and the AMSR2 instrument on JAXA's GCOM-W1 satellite. Active remote sensing data used in soil moisture estimates come from the Canadian Space Agency's (CSA) RADARSAT and will soon be available from NASA's Soil Moisture Active-Passive (SMAP) mission (to be launched in 2014). The fusion of accurate low-resolution products with higher-resolution (yet noisier) radar products is expected to yield an accurate high-resolution dataset that will bring technical possibilities closer to observational requirements. To secure the gains recently made, soil moisture observational programmes by satellites need to be sustainable and supported by a global observational network. A set of standardized procedures for measuring in-situ soil moisture and for using these datasets when validating satellite data is also necessary.

River discharge measurements are essential for water management, the design and operation of engineering works (dams, reservoirs, river regulation), and various water-related services (navigation, flood protection, water supply for irrigation, municipal or industrial water use, ecosystem management). Flood-protection programmes rely on accurate river discharge measurements and forecasts. From a scientific perspective, streamflow integrates all of the processes (e.g., runoff and evapotranspiration) taking place over the area of the basin upstream from the gauge and provides one hydrologic output variable. While in-situ methods are currently the most cost-effective and reliable option for streamflow measurements, the lack of national funding to support networks and the lack of data-sharing have led to an erosion of the capability to carry out global discharge monitoring and assessments. Motivated by concerns over the sustainability of the current in-situ network and the inability to fully support Integrated Water Resources Management (IWRM) due to a lack of data-sharing, efforts are directed at expanding the capability of satellite remote sensing to measure river discharge.

Some centres utilize satellite remote sensing solutions (e.g., the Dartmouth Flood Observatory) to document floods. Candidate remote sensing sensors for monitoring river discharge include imaging sensors that document water extent and lidar or radar altimeters that can measure river heights. The imaging radar altimeter envisioned for the Surface Water and Ocean Topography mission will be able to combine the measurements of surface water extent with water height, including measuring the surface slope along the river channel. The accuracy of discharge measurements primarily comes from labour-intensive calibration of the stage height measurements. Remote sensing solutions that still require surveying on the ground will also be costly.

Continental **surface water storage** pools (lakes, reservoirs, floodplains, wetlands, river channels) are home to aquatic ecosystems. Standing water bodies are particularly poorly monitored due to their complex spatial configurations, combined with their innumerable occurrences and high temporal variability. Monitoring the tens of thousands of high-latitude lakes and the vast floodplains and wetlands surrounding and interacting with large tropical rivers (e.g., the Amazon or the Congo) presents special challenges. Reservoirs, with their known geometries, could be a more accurate means to monitor water bodies and fluxes; however, data exchange for reservoir operations is practically non-existent.

Groundwater, which is becoming a more important source of water in many areas, is removed by natural processes (discharge) and groundwater pumping and is replaced, in whole or in part, by recharge, which is at a maximum during wet periods. Methods for inventorying groundwater, for assessing changes in its availability, and for reliable predictions of future change are needed for effective groundwater management. Groundwater measurements are collected in many countries but few countries share these data with the International Groundwater Assessment Centre (IGRAC), the designated global groundwater data centre. In the absence of a global groundwater data system, IGRAC has developed a Global Groundwater Monitoring Network (GGMN) programme, which facilitates periodic assessments of changes in groundwater quantity and quality by aggregating information and analysis from regional experts.

While groundwater cannot be directly measured from satellite or other remote sensing systems, the measurement of gravity variations by the Gravity Recovery and Climate Experiment (GRACE) twin satellites can be related to groundwater variations when combined with a land surface model. The use of satellite- and model-based estimates of groundwater could be markedly improved in the coming decade by the launch of GRACE II and a strong commitment to sharing groundwater data internationally.

Many **cryospheric variables** are needed to support climate studies and water resource management at mid and high latitudes. In particular, data on snow cover and snow water equivalent, river and lake ice, sea ice, glaciers and ice caps, ice shelves, ice sheets, and frozen ground are needed for water resources management and strategies for adapting to climate change. Some of the most convincing evidence of climate change comes from the reductions that have been reported in permafrost, seasonally frozen ground, river and lake ice, ice sheets and glaciers, and snow cover. Monitoring retreating glaciers is particularly important for assessing the impacts of climate change and predicting its effect on freshwater resources.

Seasonal snow cover and glaciers accumulate large amounts of snow over the winter and, through melt processes, make it available in the following spring and summer. For operational water managers at mid- and high latitudes, measurements of snow water equivalent (SWE) are particularly important for estimating spring and summer water supplies and spring flood potential. Reduced winter snowpack can be a precursor of drought. Local snow processes such as drifting, blowing, sublimation, and aging add to the heterogeneity of snow conditions and the non-representativeness of point measurements. Satellite data on snow cover extent and snow water equivalent (SWE), primarily from Landsat, MODIS, GEOS, AVHRR, and AMSR satellites, provide geospatially-consistent data for many key regions. However, SWE, which is derived primarily from passive microwave measurements, is complicated by surface roughness, snow temperature, and other factors. In the future, ESA's planned CoReH2O, with the dual-frequency-polarization Synthetic Aperture Radar system, will provide an opportunity to obtain high-resolution SWE observations over mountain and polar regions.

Water quality is addressed by assessing the suitability of water for various uses or processes where the standards for water quality are defined for each particular use. Water quality is a global problem but the extent of the problem is not well-known due to the lack of observations in many parts of the world. By far, the most significant cause of water quality degradation and subsequent decline of aquatic systems are human activities such as the discharge of untreated waste and industrial activities.

Water quality monitoring and assessment programmes are needed to provide up-to-date information on changing water quality conditions. Unfortunately, many countries lack the technical, institutional, and financial resources and infrastructure to conduct proper assessments. Water quality monitoring relies on in-situ discrete water sample collection, field measurements, laboratory analysis, in-situ continuous measurements, and remote sensing methods ranging from sensors placed just above water to space-based satellite observations.

In-situ measurements are the basis for ensuring that local water complies with water quality standards. The United Nations Environment Programme (UNEP) Global Environment Monitoring System (GEMS) Water Programme provides the most complete archive for data on the quality of freshwater. It is maintained in partnership with government and non-government organizations. Through its information system (GemStat), GEMS shares in-situ surface and groundwater quality data recorded at more than 3,800 monitoring sites located in 137 countries since the late 1970s.

Satellite remote sensing is emerging as a potential alternative for assessing some types of water quality. Currently, remote sensing applications are limited to measuring selected substances or conditions at coarse resolution and infrequent revisit times. This monitoring relies on the detection of changes in optical and/or thermal characteristics of the surface water properties. Directly measureable water quality variables include surface temperature, chlorophyll and cyanobacterial pigments, coloured dissolved organic material, Secchi disk transparency, turbidity and aquatic vegetation, and variables such as primary productivity and sediment fluxes, which can be derived from these data. Although remote sensing provides geospatial consistency and regular repeat visit times, in some areas the images are often affected by cloud contamination. Furthermore, satellite water quality sensing can only be successful when satellite data are used in combination with ground-based water quality monitoring, which is critical for calibration and verification.

Rivers are responsible for the transport of the majority of **suspended sediments** and their associated contaminants, such as metals and nutrients, to the ocean. Thus, river sediment transport strongly influences the quality and biodiversity of surface waters, riparian environments, and the functioning of coastal zones. Sediment data, which describe the wide range of sediment processes occurring in the environment, need to be collected, archived, and analyzed so that the linkages between river and lake processes and water quality can be fully understood.

Interoperability and Integration

Interoperability between data and information systems is a core GEO principle that affects water data, from acquisition and quality control to data exchange and information systems (such as the GEOSS Water Portals) and data assimilation systems for prediction applications. Quality assurance is a necessary step to ensure that the data collected at a specific location are reliable and produced at the same standard as they are elsewhere. Proposed approaches to quality assurance for water data are modelled after the approaches used for climate data. This approach assumes that standardized databases are made available for quality-checking, an assumption that does not hold at present for all water datasets. The raw radiance data collected by satellites must be transformed into meaningful data and made readily accessible. The calibration and validation of satellite data products is usually performed against different kinds of target data (observation) products such as ground-based in-situ observations, aircraft-observed data products from satellite underflights, geophysical model-simulated data products, and inter-comparison with other satellite-based data products. Calibration is an ongoing requirement because satellite orbits change and sensors degrade. To ensure that the calibration process is effective, it is critical for in-situ water cycle data to be collected in a consistent way and that it is made freely available for calibration purposes.

The acquisition, archival, and distribution of data relies on interoperability and the comprehensive application of GEO data-sharing principles. Users in all parts of the world expect to have real-time access to adequate satellite and in-situ data. Often this is not possible because of administrative policies, the uneven distribution of observing stations, and delays in collecting, quality-controlling, and processing the data. Data management challenges include the management of large volumes of diverse data types; lags in data dissemination; the provision of advisory services; acquisition of detailed metadata describing the data and data products; widespread use of non-standardized data exchange formats and transmission protocols and incompatible data standards; lack of reprocessing of remote sensing products; difficulty in accessing older hydrological records; uneven application of quality assurance; and declining in-situ network densities in many countries. Data archival issues include those arising from inadequate coordination; lack of standardization; different languages of data exchange; and database protection legislation, policies, and practices. In some cases, this Report proposes approaches to solving these challenges, but more frequently it recognizes the importance of working with GEO Members to develop solutions that can be implemented in the economic and social context of the problem area.

The issues of data integration, distribution, and access need to be addressed by a cross-cutting, integrated data management system that can integrate multiple variables, fragmented observing networks, and largely non-standardized archiving approaches. Data management needs to be objective-driven, with metadata databases that can be built around priority applications. A number of these needs are being met by World Water Online and Water ML2, innovations developed by the U.S. Consortium of Universities for the Advancement of Hydrologic Science Inc. (CUAHSI).CUAHSI uses Open Geospatial Consortium standards for web-based services, publishing metadata, and time series for hydrologic data.

End-user needs and requirements are best serviced through products that represent the results of data integration and modelling water cycle processes. A number of water cycle variables are not observed directly by present technology due to a lack of capability (e.g., sensors do not exist). These variables need to be estimated and computed using mathematical formulations, algorithms, and models that assimilate available observations. Predicting hydrological and hydroclimatic water cycle processes requires data integration and data assimilation for the initialization of complex Earth system models. Most users require subsets of integrated data analysis and/or model output that feed into their specific decision-support tools and protocols. The CEOS Water Portal, developed by JAXA as a distributed data system for the Data Integrated Analysis System Program, provides access to satellite, in-situ, and model output data in order to satisfy these user requirements. For improving data interoperability, we also need to develop a system for identifying the relationship between datasets by using ontologies based on technical terms, concepts, and geography. User services will be further enhanced by the sixth GEO Architecture Implementation Pilot initiative, which focuses on user services.

GEOSS supports interoperability through mechanisms such as the GEOSS Common Infrastructure (GCI) and the GEOSS Data CORE (Collection of Open Resources for Everyone). Components central to the GCI include the Components and Services Registry, the Standards and Interoperability Registry, and the Standards and Interoperability Forum, each of which develops approaches to interoperability appropriate for its different functions. The GEOSS Architecture Implementation Pilot initiatives develop new process and infrastructure components for the GCI and the broader GEOSS architecture. The Water Strategy identifies ways whereby the Water community can more effectively influence and interact with different components of GEOSS to influence its priorities.

There is also an ongoing need for detailed data to validate land surface, hydrologic, and atmospheric models, data assimilation systems, satellite measurements, and algorithms. Small instrumented basins and supersites are needed in a variety of climate zones and biomes to serve as validation sites, providing representative, continuous observations of surface moisture and energy fluxes, along with data on sub-surface moisture in both saturated and unsaturated zones. These data should be collected over catchments large enough to allow for closure of the surface water budget. These continuous observations need to be supplemented by periodic rotating field campaigns that integrate surface, aircraft, and satellite observations.

The GEOSS Water Strategy addresses observational requirements for early warning and prediction systems to provide improved decision support during floods and droughts. Water data are essential in many SBAs for decision support. The GEOSS Water Strategy explores three areas of support for decision-making, including

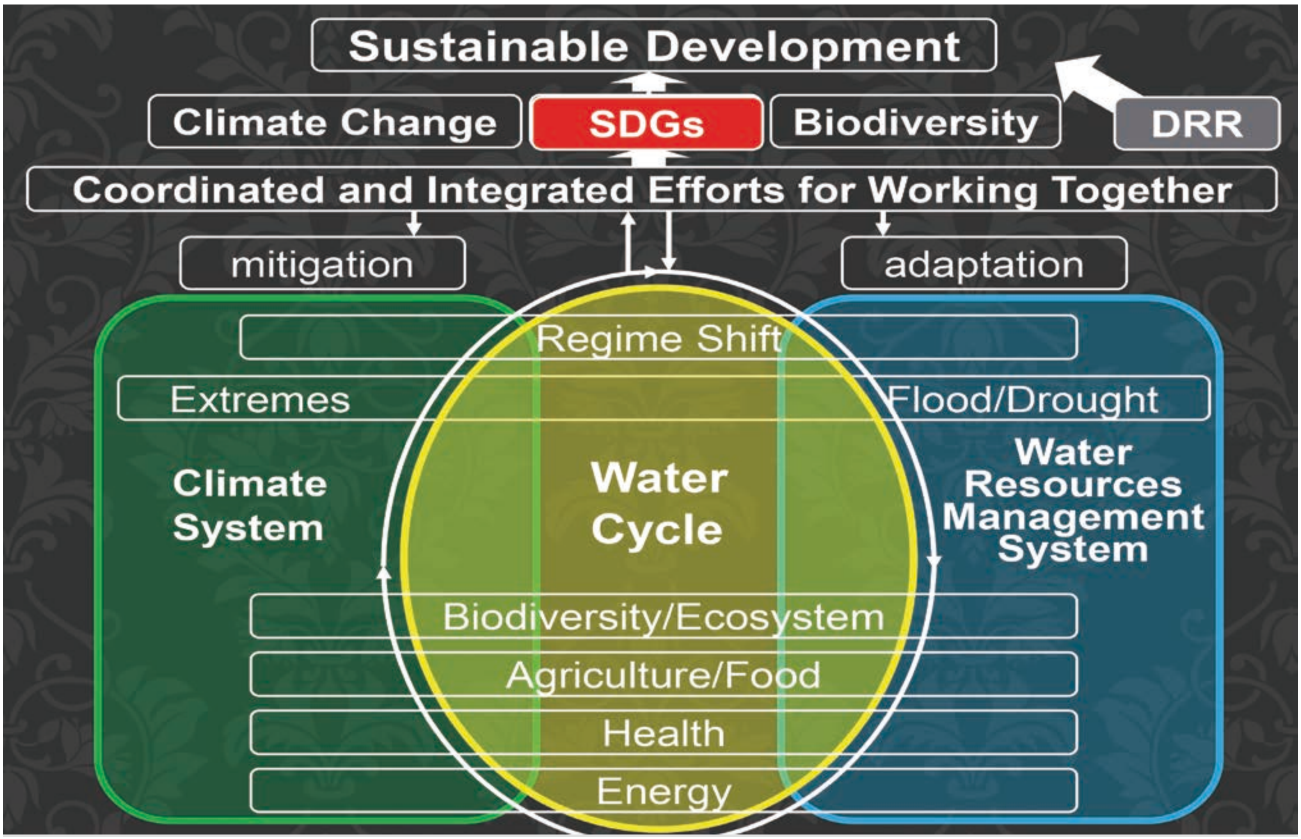

Figure 2. Concept design outlining the role of the Water Cycle Integrator within the framework of international environmental objectives. (Courtesy of T. Koike, University of Tokyo.)

drought monitoring, early warning systems for floods, and climate change monitoring for adaptation. One of the goals of the GEOSS Water Strategy is to enable observational and prediction communities to act more cohesively. Combined/integrated (in-situ and satellite) observations will be required for regional to global data coverage for monitoring and prediction systems. Accuracy in early warning systems is particularly critical since they trigger costly evacuation decisions. The GEOSS Water Strategy promotes the development of platforms and portals around themes such as floods, droughts, information support for climate change adaptation, water security, and systems to optimize the use of water for water, energy, and food security. The Strategy's role in such decision-making frameworks is to facilitate the access to and transfer of all useable observations, information, and model results to support the decision-making process.

This Strategy proposes ways to move beyond interoperability to the integration of observational systems. It is very difficult for analytical and prediction systems to characterize and track the water cycle system in a manner that captures the complexity and harmony of the natural system. However, this seamless integration is a goal for observational and prediction systems because it enables dependent water resource systems to be managed in an integrated way for the benefit of nations, communities, and the environment. Moreover, integration is important because it enables providers to maximize the benefits derived from Earth observations, to minimize the duplication of efforts, to develop more robust decision-support systems, and to reduce the uncertainties in resource management decisions made in data-sparse areas. In particular, the GEOSS WaterStrategy promotes integration for data products that bring together in-situ and satellite observations, for measurements and process understanding to provide a more complete system representation to improve modelling and prediction, and for the management of water resources by engaging experts and stakeholders from all components of the water resources system (surface water, groundwater, water quality).

The Water Cycle Integrator (see Fig. 2) is an important conceptual framework for integration among Water and the other SBAs. It also provides a set of tools that promote a harmonized approach to collecting, analyzing, and interpreting data for water management. The Report recognizes that water is the connector between the climate processes in the atmosphere, oceans, cryosphere, terrestrial carbon cycle, ecosystems, and sea level rise, and the Societal Benefit Areas, including agriculture and forestry, health, energy, human settlement and infrastructure, and the economy.

Data assimilation plays a key role in integration because it combines observations within a dynamical

Table 2. Primary capacity development needs across different geographical areas.

	Africa	Asia	Latin America	Europe	North America	North Eurasia	Australia
Floods	X	X	X	X	X		X
Droughts	X	X		X	X	X	X
Water storage	X		X		X	X	X
Water quality	X	X	X		X		
Climate change and adaptation	X	X	X	X	X	X	X
Water for the environment	X	X	X	X	X	X	X
Water for health	X	X			X		

model that provides time continuity and coupling between the estimated fields. Both observations and model predictions are imperfect and data assimilation can use the two synergistically to provide more accurate results. Satellite-based hydrological data are becoming increasingly available and, despite slow increases in our understanding of their observational errors, can be used with models to obtain an accuracy level not possible through the use of the independent outputs for individual variables. Frameworks for operational services could be strengthened by integrating research results and experimental products into their data flows for evaluation purposes. For example, GEWEX develops new products that could be used within a GEOSS test bed for evaluation purposes.

Capacity Development: Individuals, Infrastructure, and Institutions

In addition to improving the effectiveness of capacities in developing countries and different user communities, an expanded capacity development activity is envisioned in this Water Strategy. These developments are aimed at improving global water management and demonstrating the value of GEO infrastructure and principles. The Water Strategy addresses the need for human capacity-building through the education and training of individuals regarding Earth observation data and products. It also supports institutional capacity development by creating a facilitating environment for the use of Earth observations, infrastructure, management and demonstrating the value of GEO infrastructure and principles. The Water Strategy addresses the need for human capacity-building through the education and training of individuals regarding Earth observation data and products. It also supports institutional capacity development by creating a facilitating environment for the use of Earth observations, infrastructure, and knowledge related to the hardware, software, and other technology required to access, use, and develop Earth observation data and products.

Primary capacity development needs across different geographical areas are shown in Table 2 (based primarily on the 2005-15 GEO capacity building needs assessments). Future GEO Water capacity development activities will build on best practices and existing successful efforts in different areas; foster collaboration and partnership, especially among developing countries, at multiple scales, and across water connections with other SBAs; address a range of end-to-end water application needs, including user requirements; data access, collection, archiving, and analysis; and product development and exchange. It will enhance the sustainability of existing and future Earth observation capacity-building efforts by increasing awareness among decision-makers of Earth observation and integration opportunities in developing countries and will facilitate the development of sustainable capacity-building efforts that address infrastructure capacity needs, education and training, and local institutional capacity.

Figure 3. A Moroccan farmer makes use of a USAID SMS advisory service to plan irrigation for his crops. (Courtesy: USAID.)

While water capacity development activities have a regional perspective that must remain a primary consideration in regional efforts, they will also contribute to central GEO capacity-building objectives. In particular, they will involve the development of training materials and courses and the launch of demonstration projects and web portals. It is anticipated that further harmonization between regional capacity development activities will be achieved through joint initiatives and, possibly, through jointly-funded projects. GEO Water Cycle activities will focus on three developing regions: Africa, Asia, and Latin and Central America. Relevant work being carried out in other parts of the world will also be encouraged.

The activities of the GEOSS Asian Water Cycle Initiative (AWCI) will continue to address four general areas: flood, drought, water quality, and adaptation to climate change. It will build toward a regional cooperative framework by involving experts from Southeast Asian countries in sharing data, models, experiences, and knowledge and implementing capacity development activities supported by the Asian Pacific Network. Other contributions by JAXA regional capacity building activities; NASA and the Nepal SERVIR node; and activities in China, such as DRAGON, will also contribute to this development.

Africa provides a rich opportunity area for water-related capacity-building efforts thanks to European, Japanese, and American efforts on that continent. The Water Strategy builds upon the GEOSS Africa Water Cycle Coordination Initiative (AfWCCI) and its goals of convergence and harmonization of observational activities, implementation of new techniques, inter-operability arrangements, and effective and comprehensive data management in support of improving water security in Africa. Work will focus on transboundary basins to advance the implementation of Integrated Water Resources Management and to demonstrate the value of GEO principles. It is anticipated that the TIGERNet Initiative, supported by ESA, Canadian Space Agency (CSA), the Council of Scientific and Industrial Research, and UNESCO, will become a more integrated part of the initiative, as will the USAID/NASA SERVIR system at the Regional Centre for Mapping of Resources for Development in Nairobi, Kenya, and other possible centres elsewhere in Africa. Other NASA projects, including the Water Information System Platforms in North African countries (see application in Fig. 3), will also become engaged in AfWCCI.

Work in Latin America will continue to build on the Centre of Hydrologic and Spatial Information for Latin America and the Caribbean's coordination activities. This group has facilitated a number of activities, including work in Belize with GEONETCast, the transfer of Brazilian soil moisture data to the global soil moisture database, and collaboration with the Water Center for Arid and Semi-Arid Zones in Latin America and the Caribbean for drought monitoring. Efforts will be made to ensure space agencies in South America play a stronger role in the overall Water Strategy implementation.

In other regions, interdisciplinary programmes of internationally-supported Earth systems and science research, such as the Northern Eurasian Earth System Partnership Initiative, will continue to support regional research projects and training programmes for young scientists. In North America, NASA will lead in capacity development activities through funded projects that promote the transfer of technology to the state level. The recent trend toward the use of webinars for training will be exploited during the coming decade, both in the Americas and around the globe.

The Water Strategy will be implemented through a coalition of partners. Partners will be engaged based on their ability to deliver on water tasks and to build connections with larger policy and implementation bodies both internationally and nationally. A targeted strategy for interacting with collaborators and organizations will be developed so that each has a clear role in the implementation of the GEO Water Strategy. Interactions will occur with GEO members (nations) and international organizations at the policy level and with experts in government agencies and departments, academia, and the private sector at the project level. At the international level, the GEO Water Task will continue to seek out contributions from and interactions with UN Water and international research and observational programmes. Other organizations and agencies expected to play major roles at the national level include CMA, ESA, EUMETSAT, JAXA, NASA, the National Oceanic and Atmospheric Association (NOAA), the U.S. Geological Survey, the European Commission, and the U.S. Water Partnership, among others. These links are needed to provide access to experts, regional networks, and funding support to data and research programmes, and to all of the other assets needed for an effective programme. JAXA and NASA have been very supportive of water activities over the past decade by providing satellite data, funding workshops, and providing Secretariat support for GEO Water coordination. A more vigorous GEOSS Water programme, as foreseen in this Strategy, will provide more benefits but require more support from GEO member countries. It is widely accepted that water resources are critical for economic development and societal well-being, both nationally and internationally. The policy and institutional environment in which these observational systems are developed and managed is the result of a mosaic of decisions that have been made over the course of many decades. In recent decades, in-situ observations have suffered from national budget cuts and the absence of a "champion" to speak on their behalf. The time has come for strong advocacy for in-situ networks and data needs. The Water community is prepared to assist GEO and WMO in moving their in-situ observing agenda forward.

Space programmes face their own challenges. In some larger countries, the responsibilities for operational satellites have been left with mission agencies, while research space agencies have led the development of research satellites. This approach has worked well in developing a rich suite of research satellites but the transition from research to operational observational systems, and the links between operational services and users have lagged because of concerns about the continuity of satellite services and budgetary considerations.

Implementation

The post-2015 GEO will provide the framework for implementing the GEOSS Water Strategy. Some approaches from the previous decade will be carried forward, while others will be reviewed, modified, and implemented, as appropriate. This review will examine the committees and working groups and the Community of Practice concept, which have served the GEO Water Task over the past decade. A more effective dialogue is required between scientists and stakeholders, both to improve the dissemination of scientific information and to learn from the experiences, knowledge, and needs of user communities. In order to strengthen user interactions and interactions across Societal Benefit Areas, more emphasis will be placed on this coordination. Efforts will be directed at seeking a more substantive and well-funded Secretariat. Anticipated work over the next few years on the definition of the GEO Water Target, Task (or Tasks), and water activities will be an important foundation for water activities in the post-2015 period.

The GEOSS Water Strategy will build upon the successes of the last decade. Some of the opportunities for moving GEO Water activities forward are the Water Cycle Integrator, which has strong support in Japan; the AfWCCI, which may be on the verge of securing funding for substantial demonstrations in different transboundary basins in Africa; JAXA's Global Change Observation Missions (GCOM) and its collaboration with the Asian Development Bank; NASA missions such as SMAP and its collaborations with USAID through SERVIR; the joint NASA/JAXA TRMM and GPM missions; ESA Sentinel missions, TIGERNet, and ESA interactions with the World Bank and the European Commission, which provides project funding for GEO initiatives. Stronger links with the WMO and UN Water would also strengthen the Water Task links with operational programmes and water policy.

Programmatically, over the next decade GEO could supplement its present support to the Water Task by providing an additional coordination capability that could bring about observational system integration, science and model integration, integrated data products, a stronger Community of Practice, increased cross-Societal Benefit Area collaboration, management system integration, and a sustained education and capacity development framework. A system for data integration and analysis is envisioned; it will include the supporting functions of life cycle data management, data search, information exploration, scientific analysis, and partial data downloading. A "work bench" concept, a virtual geographical or phenomenological space in which experts and managers work together to use information to address a problem will provide opportunities for sharing data, information, and applications in an interoperable way, exchanging knowledge and experiences, deepening mutual understanding, and working together effectively among various partners. While software development will be needed to support these activities, it will also be necessary to develop the appropriate expertise to utilize the system fully. This broader framework will serve as one of the primary background systems that will utilize advances in different areas and ensure they are integrated into a useable system for the benefit of national, basin, and global decision-makers and communities.

Recommendations from the GEOSS Water Strategy Report

Based on the assessments in the GEOSS Water Strategy: From Observations to Decisions report, and summarized in the foregoing Executive Summary, the following recommendations were developed. Recommendations for each major functional group are summarized below.

Enhancing User Engagement

A.1. A study of the methods for assessing the requirements and needs of users should be undertaken by identifying precisely how different observational data types and derived information products for end-applications sectors are used in decision-making tasks. Based on the results of this study, an analysis should be carried out to design the best available integrated observing technology and data analysis systems that deliver data products in a form that satisfies the input requirements of the end-user decision-making process. This would entail some well-designed workshops, with strong representation of the user community.

A.2. GEO Water should develop and launch a continuous process to identify, articulate, and further refine user needs in the various water communities from the local scale to the global scale. The process should build upon existing work by GEO such as the Water SBA Needs report; utilize existing draft taxonomies of user types such as the one developed by the GEO User Interface Committee; interact with communities of users in professional organizations such as the International Water Resources Association and with UN agencies such as UNESCO and UNEP; identify and gain water-related information from other relevant GEO Societal Benefit Area connections, GEO networks, GEO projects, and Work Plan activities; publish findings regularly; and prepare a sustainability strategy to support user engagement though an ongoing consultative process.

A.3. A global-scale coordinated initiative should be developed and implemented to advance the future use of satellite remote sensing for water quality applications. Factors such as the community requirements for continuity of existing satellites, development of new and improved sensor/platform technology, algorithm development, calibration/validation activities, and improvements in open and free data accessibility should be part of this initiative.

A.4. An inventory of current data services supporting GEO Water should be developed. This inventory should include information on the characteristics of available services and their data needs.

A.5. An evaluation should be undertaken of the data holdings of global data centres to determine which centres have and make available data that can be effectively used to assess the magnitude and frequency of extreme events and the ability of global and regional models to simulate water cycle processes.

A.6. A review of the water resource managers' needs should be undertaken to gather water cycle information related to extreme values. Data collection and information systems should be assessed to ensure these data are available for research activities.

A.7. GEO members should support the development of water cycle solutions integration in order to meet the needs of water resource managers and other end-users by translating water cycle observations into actionable products.

A.8. GEO should develop a strategy to ensure that future water cycle solution integration activities utilize techniques to quantify uncertainty in various products delivered to end-users and engage with these end-users to enhance the use and understanding of these supplemental error and uncertainty products through a risk-based approach to water management.

Expanding data acquisition (General)

B.1. An integrated monitoring system should be developed to track consumptive and non-consumptive water use and its changes using satellite and in-situ observations along with models that relate water use to land cover and demographic information.

B.2. Based on the principles of participatory monitoring, in order to assess the state of groundwater and its changes, IGRAC's efforts to establish the Global Groundwater Monitoring Network should be accelerated and linked to the validation of remote sensing data. Special attention and support should be directed at developing a global hydrogeodetic repository that links directly to the GGMN, providing additional groundwater data and information.

B.3. The Global Climate Observing System's participants should be invited to undertake a joint study with GEO to assess the current prioritization of observational and modelling efforts for water cycle variables as part of its support to the UNFCCC.

Advancing satellite data acquisition

C.1. The feasibility of developing a Water-Train satellite constellation should be assessed. This suite of satellites would be modelled after the A-Train, providing a space segment of an observation system that would capture all fluxes and stores of the water cycle using a diverse suite of platforms and instruments. This system would operate as a Virtual Water Cycle Constellation.

C.2. Satellite missions such as those in the A-Train and the planned EarthCare and GCOM-W2 missions and field experiments should be closely coordinated to measure cloud properties, with the goal of providing data for the study of precipitation processes and energy budgets. Furthermore, these satellite measurements should be transitioned into operations and sustained in the long term.

C.3. Advanced satellite technologies, such as hyperspectral infrared and millimetre/sub-millimetre and microwave radiometres, should be promoted to improve horizontal and vertical resolutions of key measurements to observe clouds, water vapour, and aerosols. As well, multi-frequency radars should be sustained and Doppler capabilities should be introduced to observe the cloud precipitation particle continuum and provide vertical velocities for critical cloud-process studies.

C.4. The coverage and quality of satellite observations should be improved to a constellation providing three-hourly (or more frequent) revisit times over the entire globe by a combination of GMI/AMSR2-class multi-channel conically scanning microwave imagers and ATMS-class multi-channel cross-track microwave sounders. These instruments are identified because they provide input data for a wide range of applications.

C.5. Space-borne precipitation radar should be made operational and next-generation precipitation radar with advanced technology should be developed. The success of the TRMM precipitation radar has demonstrated that space-borne radar observations are among the most valuable multi-purpose observations of precipitation. Although the GPM Dual-frequency Precipitation Radar is expected to extend this result, a long-term plan is needed for using these radars operationally and a long-term commitment is needed by GEO members to ensure a continuity in the supply of these instruments.

C.6. A commitment by CEOS, GEO, and their members to provide requisite thermal band imaging sensors on satellites is needed. Routine Land Surface Temperature (LST) observations at high spatial/low temporal (e.g., LANDSAT), moderate spatial/temporal (e.g., MODIS), and low spatial/high temporal (e.g., GOES, Meteosat, and other geostationary platforms) are essential in order to improve ET estimation from the field to the continental and, ultimately, to the global scale. Responsible agencies need to process and make available LST datasets from GEO satellites so that these products can be used to map ET in near-real time. More frequent revisit times (four-day) along with higher resolutions (finer than 100 metres) through multiple LANDSAT-type satellites are needed to compensate for data loss from clouds and water management requirements.

C.7. GEO and CEOS should facilitate the planned NASA/German Aerospace Centre (DLR) joint GRACE II mission that will follow the current GRACE Twin (expected launch date of August 2017). GRACE II is expected to provide improved accuracy and resolution due to technological advances made during the past decade. This mission is essential for ensuring continuity of the many GRACE applications that have emerged. The U.S. National Research Council's Decadal Survey Study's call for a continuation of GRACE follow-on missions with lower-orbit, drag-free satellites with laser interferometry that yield higher spatial resolution data is also a priority for GEO.

C.8. Plans for a mission optimized to measure cold season processes and variables from space drawing on experience with algorithms for cold season microwave measurements and cold season field projects should be developed.

C.9. Attention should be given to the further development of multichannel satellite sensors that will be able to provide freeze/thaw patterns under different vegetation conditions.

C.10. A feasibility assessment should be undertaken to determine the benefits and technological difficulties of designing a hyperspectral satellite mission focused on water quality measurements.

Strengthening in-situ data acquisition

D.1. In-situ observational networks should be strengthened to ensure that the required data are collected and made freely available to the international community. GEO and WMO members should both engage in assessing gaps in their national networks and develop a plan for addressing those gaps. As an operational research activity, approaches should be studied to take advantage of the supplemental observational networks (for selected variables) that are maintained by volunteers, education systems, and local governments.

D.2. A global observational network dedicated to clouds and water vapour should be established. This network should include high-calibre radiosonde stations (some collocated with Baseline Surface Radiation Network stations, others in critical areas lacking such data, particularly equatorial zones), GPS, and lidars. These observations should be freely available to the scientific community.

D.3. National precipitation gauge networks should be strengthened and all measurements should be collected, archived, and made available to the international community. Special attention should be given to strengthening the gauge networks at high latitudes where more accurate snowfall information is needed for evaluating changes arising from climate change. A study should be undertaken of approaches to take advantage of the supplemental gauge networks that are maintained by volunteers, education systems, and local governments.

D.4. Additional support should be given to expanding the in-situ collection of ET flux measurements and providing adequately archived and operational flux data that is networked and accessible through the Internet. This effort would be accelerated by recognition of ET as an Essential Climate Variable or, possibly, as an Essential Water Variable.

D.5. A strong rationale should be developed in order to encourage increased financial commitments by GEO members and other nations to continuous operation and expansion of soil moisture networks. A strategy reviewing the optimum network size and trade-offs between the number of stations and equipment upgrades and demonstrating the benefits of soil moisture in key applications would be part of this rationale. The strategy should also review the benefits of supersites. It should also address the full spectrum of environmental variables would be measured. Support is also needed for follow-on missions such as GCOM-W2, which are necessary to provide long-term global soil moisture measurements.

D.6. GEO Water activities should include projects that will strengthen advanced monitoring networks, data-sharing, and quality control for groundwater measurements and data.

D.7. Efforts should be made to supplement the current network of snow-depth observations from selected manual climate-observing stations and global, daily snow-depth analyses with weekly satellite measurements of SWE.

D.8. Given the many threats to groundwater quality that arise from salt water intrusion, seepage of contamination, nuclear waste, and fracking, among others, GEO Water should clarify the needs for groundwater quality data and develop a plan for collecting the required observations.

D.9. A workshop should be organized to address the application of in-situ measurement techniques and data in water quality assessments. The workshop would explore ways to develop harmonized approaches and best practices for water quality measurements and ways to benefit from technological advances. Workshop contributors should include experts in the fields of sensors, data communication, and management, and practitioners operating sensor networks.

D.10. Plans should be developed to rescue historical and local records and to make them available for historical water cycle studies and the assessment of local water issues.

Encouraging and conducting research and product development

E.1. Research on individual-sensor and multi-sensor algorithms should be supported. Operationally useful estimates from individual sensors over complex terrain, icy/snowy surfaces, coast, and land (in general) are priorities that require substantial development work. Improved algorithms for the objective, optimal combination of precipitation observations from widely disparate sources must see continued research and development, potentially including assimilation approaches. Conversely, as an additional initiative, combinations incorporating both observations and numerical model/reanalysis estimates should be supported. This action should particularly benefit polar and cool-season mid-latitude regions, since the numerical results tend to validate better in those conditions.

E.2. Advanced cloud and water vapour parameterizations should be developed for weather and climate models in tandem with new observational capabilities, with the goal of significantly improving their integrity and building confidence in the resulting model predictions.

E.3. Methodologies and best practices should be developed for using existing soil moisture in-situ data to validate satellite measurements. More upscaling and downscaling studies are needed to validate results against in-situ network measurements. A global-scale project bringing together in-situ networks, satellite observations, and appropriate ancillary data should be launched to achieve this goal.

E.4. Work on radiative transfer models should be expanded. The spectral properties of soil samples should all be analysed for and reported back to a central body (e.g., the ESA Soil Moisture Climate Change Initiative). Moreover, vegetation information used in retrieval algorithms needs to be verified regularly on site. For this, vegetation observations are required at selected soil moisture stations to provide continuous assessments of the vegetation dynamics, which directly influence the soil moisture retrievals.

E.5. High priority should be given to generating improved global soil texture maps in order to improve modelling and retrieval of soil moisture. Furthermore, a more concerted effort is needed to develop an integrated soil moisture product.

E.6. An inventory of all surface water data archives, including both natural and man-made lakes, reservoirs, and wetlands, should be developed. Based on the details of this inventory, a plan for implementing a process to establish protocols for collecting data and metadata on surface water stores should be developed.

E.7. A dataset including bathymetry of all surface water bodies around the globe should be developed, possibly under the leadership of UN Water.

E.8. The feasibility of establishing a monitoring system of man-made reservoirs should be assessed. The end result of this review could be the use of current and planned data systems to provide a real-time monitoring system of the surface water in storage.

E.9. An initiative should be launched to assess the feasibility of combining in-situ measurements and GRACE satellite data to produce an integrated groundwater product on a regional basis.

E.10. Priority should be given to research on the development of algorithms and new sensors to measure the water equivalent of snow on the ground under a wide range of vegetation conditions. Furthermore, it may be possible to design improved algorithms to more effectively utilize existing data sources.

E.11. An initiative should be launched to develop a research-quality dataset of the climatology of snow properties, initially regionally, and eventually globally, integrating in-situ, microwave, and visible snow measurements. Efficient ways should be found for distributing the data among all interested researchers.

E.12. GEO Water and the IGWCO CoP should explore the needs for data to assess changes in the frequency and probability distributions in the extremes in water-related variables and parameters, especially those that impact the availability of freshwater resources.

E.13. User support should be developed and maintained at the science and parameter level. Work should also continue toward a more distributed and standards-based information system that will free data producers from having to support format and server issues.

E.14. GEO members should strengthen support for water cycle data integration activities such as LandFlux-EVAL to assure that satellite-based estimates of critical water and energy cycle variables are of the highest quality.

E.15. GEO should work with WCRP and other relevant organizations to promote water-cycle data and model integration activities that include critical water cycle processes corresponding to current and future water cycle observations, such as terrestrial water storage (i.e., snow pack, soil moisture, dynamic water tables), surface water elevations and discharge, and isotopes/fluorescence.

E.16. GEO should promote water cycle data model integration activities to support future water cycle observing system simulation experiments that can be undertaken in collaboration with the international GEOSS community to quantify the impact of each element in an integrated water cycle observing system.

Facilitating data sharing and common standards

F.1. Institutions maintaining archives of water cycle variables should apply modern standards of open data stewardship. High-quality products require consistently processed, long-term datasets that are readily available, preferably including one version in the original coordinates (for example, swath-footprint for satellite data). As new quality-control procedures and algorithms are developed, these archives should be reprocessed to ensure that the community has ready access to consistently processed estimates for the entire period of record.

F.2. A set of standards or protocols should be developed for ET measurements, databases, and metadata, including FLUXNET and other tower networks. Tower operators providing data for research and operations should ensure they meet these standards and also make available sufficient metadata along with objective evaluations of their datasets. GEO members should provide long-term support to key stations in their countries to maintain a reference network for flux tower measurements.

F.3. An international cooperation and coordination mechanism should be developed to advance the technical implementation of global sediment databases and data portals. This mechanism should include existing data initiatives and build on the GEOSS Common Infrastructure as a framework for bringing together all relevant Earth observation data.

F.4. A review of the WMO regulations on hydrometeorological data exchange should be undertaken to assess their effectiveness in enabling the exchange of data with the Global Runoff Data Centre and the Global Precipitation Climatology Centre and enabling the exchange of data between countries.

F.5. Efforts by GEO members to support initiatives leading to interoperability should be accelerated. At the same time, users and dataset developers need flexible, low-burden standards at all levels to enable easy adoption of the interoperability concepts being developed.

F.6. GEO should develop plans to ensure that vitally needed telecommunications infrastructure be established in order to ensure data availability in the developing world and to support the transmission of high-volume satellite datasets during the coming decades.

F.7. GEO Water should work with the Climate SBA to promote the development and use of Geographic Information Systems-compatible water and climate data records on extremes (droughts and floods) to provide real-time and early warning information to decision-makers, and data for research by the hydrological climate and ecological communities.

Expanding capacity development

G.1. The use of ET products in international end-user decision-support tools through workshops and pilot projects should be expanded. This could be done through the careful design of training modules and demonstration projects related to ET within the GEO Water capacity development activities.

G.2. A web-based clearinghouse should be established for water cycle training materials, primarily intended for professionals and pre-professional students. This inventory would facilitate improved training and allow capacity building activities to have a central site and provide access to training materials appropriate to a variety of audiences that have been independently developed across many organizations.

G.3. Periodic GEO Water Strategy capacity-building workshops should be convened, without specific geographical focus, to develop a broad strategy for GEO Water capacity-building. These workshops should focus on developing synergies between the work done in different geographical areas, a means for more effectively transferring the results from one region to another, and common training materials that can be used in different geographical areas.

G.4. GEO Water and the IGWCO CoP should undertake a feasibility study to determine how Earth observations can be integrated with other data types to produce a system for monitoring water use.

Appendix A

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