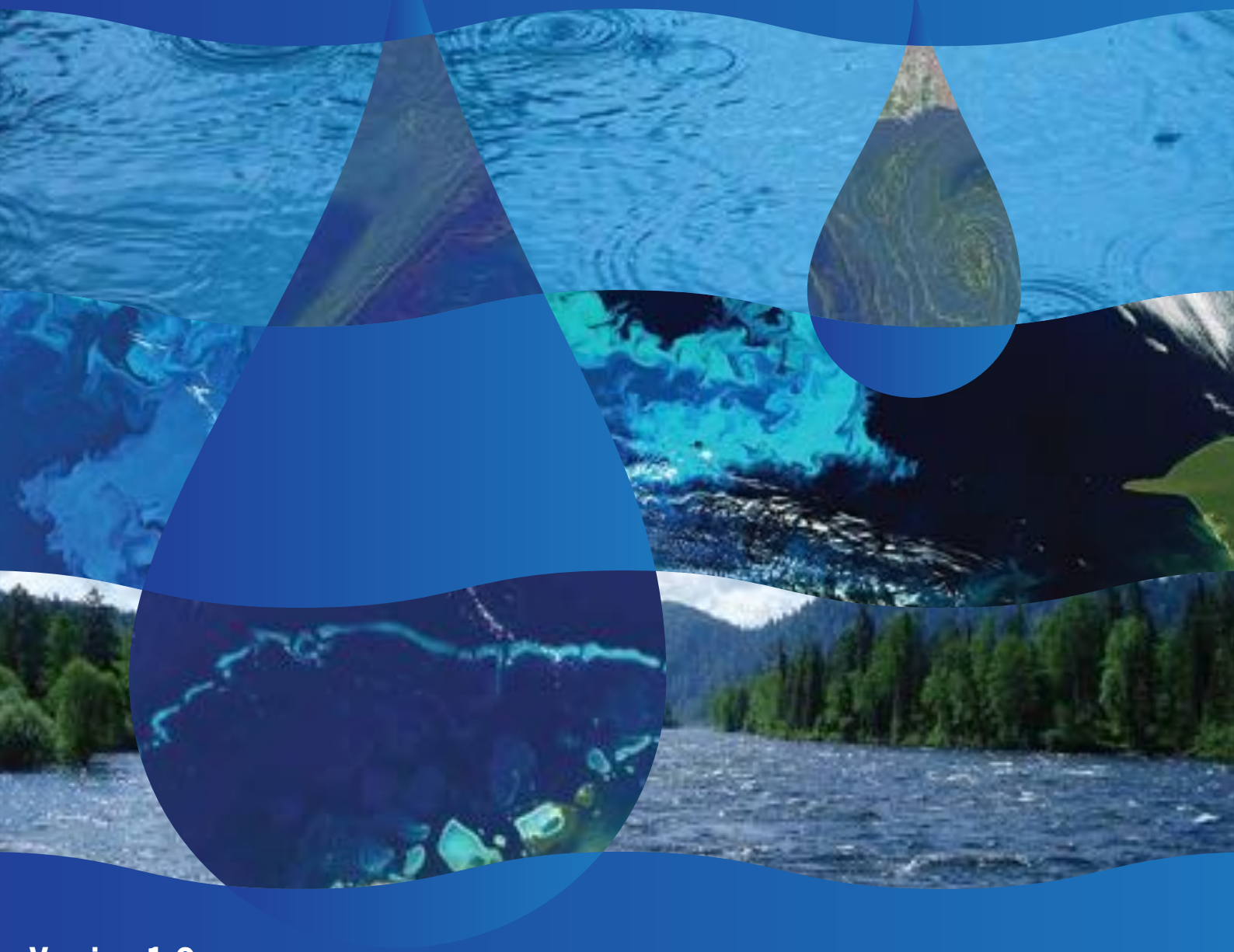
CEOS STRATEGY FOR WATER OBSERVATIONS FROM SPACE

CEOS Response to the GEOSS Water Strategy Recommendations



Version 1.0
October 2015

CEOS Strategy for Water Observations from Space

The Committee on Earth Observation Satellites (CEOS) Response to the Group on Earth Observations System of Systems (GEOSS) Water Strategy

Developed under the auspices of the Water Strategy Implementation Study Team

V1.0 for CEOS Endorsement

October 2015

Contents

1 Introduction

1.1 Purpose

This report has been prepared by the Committee on Earth Observation Satellites' (CEOS) and is a direct response to the needs expressed in the Group on Earth Observations System of Systems (GEOSS) Water Strategy (2014). The Group on Earth Observations (GEO), which is coordinating the development of the GEOSS, addresses water as one of its nine Societal Benefit Areas. The Water Strategy report outlines a strategy 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. It suggests a framework for guiding decisions regarding priorities and strategies for the maintenance and enhancement of water cycle observations; enables improved water management based on a better quantification of fluxes and stores in the global water cycle; promotes strategies that will facilitate the acquisition, processing, and distribution of appropriate water data products; provides information on expertise, information systems, and datasets to the global, regional, and national water communities; and increases the availability and use of data, information, and indicators of the quality of inland and near-coastal waters to support operational water quality decision-making.

The GEOSS Water Strategy gives priority to the use of water-related Earth observations in six critical theme areas. These themes include the global security of domestic and useable water supplies, the adaptation of water resource systems to the impacts of climate change, the water-related health and welfare needs of the poor, protection from hydro-meteorological extremes (including floods and droughts), the information needs of the security nexus of water, energy, and food, and access to water for ecosystems and biological systems.

1.2 Audience

The main audience for this report is CEOS and the organisations that comprise its membership, hereafter referred to as CEOS Agencies. It will serve primarily as an internal document to highlight priorities, identify opportunities for improved coordination and to create synergy, and provide guidance in planning for future water-related observations.

1.3 Approach

A CEOS Water Strategy Implementation Study Team (WSIST) was established by the 28th CEOS Plenary (Tromsø, Oct, 2014) to prepare this CEOS response to the GEOSS Water Strategy Report. This draft report was prepared by the WSIST by consolidating responses from each of the CEOS Agencies with an active interest in implementation of the Water Strategy recommendations. The draft report will be updated by consolidating inputs and

feedback from all participating CEOS groups and Agencies – with the aim of endorsement of the report at the 29th CEOS Plenary (Kyoto, November 2015).

The GEOSS Water Strategy is a comprehensive publication with recommendations of relevance to a large number of communities and actors, in addition to CEOS and its Agencies. The WSIST has focused only on those 22 recommendations that are of direct relevance to CEOS and the planning and coordination of satellite-based observations. The GEOSS Water Strategy Report adopted the following categories for presentation of their recommendations:

A enhancing user engagement

B expanding data acquisition (general)

C advancing satellite data acquisition

D Strengthening in-situ data acquisition

E encouraging and conducting research and product development

F facilitating data sharing and common standards

G expanding capacity development

For ease of tracking, the WSIST Report employs these same categories. However, the 22 recommendations to which CEOS has responded fall only in categories C, D, E, F, or G. In each case, CEOS has described its proposed approach to address the recommendations from the GEOSS Water Strategy. Some of these recommendations require substantial and sustained programmatic and financial commitments in support of a multitude of societal needs for water information and supporting observations from space. Consistent with the nature of the CEOS organisation and with existing observation strategies of CEOS, the response in each case should be interpreted as requesting best effort support from each contributing agency/government. The CEOS response provides an effective framework for monitoring and managing progress towards the GEOSS Water Strategy requirements but is ultimately dependent on the priorities and capacities of individual agencies and their satellite observing programmes.

1.4 Contents

The following sections systematically address the recommendations and CEOS response according to the GEOSS Water Strategy categories:

Section 2: Advancing Satellite Data Acquisition

Section 3: Strengthening In-situ Data Acquisition

Section 4: Encouraging and Conducting Research and Product Development

Section 5: Facilitating Data Sharing and Common Standards

Section 6: Expanding Capacity Development

Section 7: Additional recommendations

In each case, the section lists the relevant recommendation, the CEOS response, along with: the time horizon for the action; the lead entity within CEOS; the contributing entities within CEOS; any proposed external partnerships.

2 Advancing satellite data acquisition

CEOS will take the lead in addressing this category of the GEOSS Water Strategy recommendations, and will solicit inputs from other groups who may also contribute.

Recommendation 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.

CEOS response:

Coordination of current and future satellite missions to satisfy validated and prioritized user requirements is a clear mission and function of CEOS. CEOS notes that mechanisms like 'Virtual Constellation' and '<x>-Train' have specific characteristics, making them suitable to solve problems under certain conditions. For example, existing Virtual Constellations already coordinate certain subsets of CEOS Agency missions to meet user remote sensing requirements across a number of domains, raising questions about how those missions would be coordinated if domain-specific (rather than measurement-specific) Virtual Constellations were to be involved. The concept of '<x>-Train' refers specifically to the coordination of satellite orbits to support observation of a particular spatial area within a close time period. CEOS is unsure whether this is appropriate across all water variables, which operate across a wide range of spatial and temporal scales - unlike, for example, atmospheric measurements.

However, CEOS notes the value of establishing and implementing appropriate coordination mechanisms to support monitoring of the water cycle. CEOS therefore proposes to respond to this recommendation by undertaking a study to identify what axes of coordination (spectral, spatial, temporal) would ultimately translate into effective production of information with the biggest societal benefit and impact. For example, such a study would examine whether increasing spatial and temporal coverage of specific important water cycle variables such as evapotranspiration is of higher relevance to users than coordinated observations.

Such a study would also take into account current capabilities and their associated spatial and temporal characteristics, as well as capabilities likely for future planned and potential satellite systems. This would include consulting with the full range of CEOS Agencies. CEOS notes that a number of existing and proposed missions, including specialist missions (such as GPM) and more general missions (such as ALOS-2, SMOS/SMAP, Sentinel-2 or Landsat) have the potential to contribute to a coordinated solution. Such a study would take particular care to ensure proposals draw on, and reinforce the need for, data from current and future operational platforms. Such a study would also identify

where gaps and overlaps in existing measurements could be addressed to better meet water requirements, and to minimise the need for new missions. It should also consider how next-generation geostationary missions might impact the temporal frequency of observations without the need for new polar orbiting missions implied by an '<x>-Train' approach. CEOS will also ensure this study links with the activity proposed in its response to C10.

CEOS notes the need for clear guidance from end users about the procedures for application of integrated data streams for each of the relevant variables - before determining what the priorities for coordination might be and what is the most appropriate coordination mechanism (such as a new Virtual Constellation). GEO Integrated Global Water Cycle Observations (IGWCO) should coordinate this input, in close consultation with CEOS to ensure its suitability.

Proposed CEOS action for C1: CEOS to undertake a feasibility study on enhanced coordination of satellite missions, data acquisition and product generation to support an integrated approach to water monitoring.

CEOS lead entity: WSIST (One year extension of the WSIST will be proposed to conduct the feasibility study)

CEOS contributing entities: P-VC (TBC), LSI-VC (TBC), SEO

Proposed external partnerships: WMO, CGMS, IGWCO

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.

CEOS response:

CEOS agrees with statements that the water and energy cycles are coupled in many ways, and proposes that this recommendation be expanded to include coincident measurement of relevant radiation fluxes (i.e., those significantly impacted by cloud presence and type).

CEOS Agencies have expressed their ability to contribute data from a range of missions of relevance to this recommendation, including VIIRS, CRIS, ATMS and EarthCare. CEOS notes that this coordination between field experiments and satellite observations already occurs in many cases, in support of existing calibration/validation campaigns.

CEOS seeks further clarity from the GEO IGWCO on additional coordination requirements, to be in a position to provide an indication of its ability to support the study goals. CEOS notes that a range of relevant missions are run in accordance with long term / fixed acquisition plans, and welcomes on-going dialogue with the GEO IGWCO on how to operate in this context.

CEOS notes that the provision of satellite measurements on an operational basis is a question for individual Agencies and their governments, but that the ability to explain how a particular mission might form part of a coherent international satellite observing system is a powerful input to funding decisions. CEOS further notes that the successful application of data from non-operational programs to deliver results to influential users, and effective communication of the impact and relevance of those applications by those users to key decision-makers, is an important step in transitioning research missions into operational programs. This is an area where CEOS welcomes the support of the GEO IGWCO in working with user communities.

CEOS Agencies have identified the potential to supply relevant field data, for example from international networks of surface flux towers, to complement better coordinated space data.

CEOS notes that Ralph Ferraro/NOAA submitted input to the GEO transitional 2016 Work Plan on Water Vapor and Clouds (and Aerosol and Precipitation) activity. The primary objective of this activity is to develop an observation strategy to improve the synergistic understanding between water vapor and clouds, and if feasible, aerosols and precipitation.

Proposed CEOS action for C2: CEOS to participate in the GEO water vapor and cloud activity, as proposed by Ralph Ferraro/NOAA.

CEOS lead entity: P-VC

CEOS contributing entities:

Proposed external partnership: WMO, CGMS, IGWCO

C.3. Advanced satellite technologies, such as hyperspectral infrared and millimetre/sub-millimetre and microwave radiometers, 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.

CEOS response:

CEOS Agencies have a number of existing and planned missions that will generate datasets which will, together, substantively address this recommendation in the medium term.

The EarthCARE/CPR mission is anticipated to be launched in 2015 or shortly thereafter, and will provide precipitation measurement capabilities for snow and ice. CEOS Agencies are developing advanced global water vapour retrievals (total column with 350m and 1km resolution), and aerosol retrievals (AOD and aerosol properties at 3km and 1 km resolutions) for the Sentinel-3 (low-earth orbit) and Sentinel-4 (geostationary) missions.

CEOS notes that the Precipitation Virtual Constellation is conducting a study to analyse post-GPM plans. A number of CEOS Agencies have already expressed in-principle commitment to GPM and other satellite-related activities that will support this goal - both for precipitation processes, clouds, and the role of aerosols with both. CEOS also notes that the JPSS/CrIS sensor will fly on J-1 and J-2.

CEOS also notes that the Ice Cloud Imager (ICI) covering the sub-mm wave range, IASI-NG a Microwave Imager (MWI) and 3MI will fly on the EPS-SG platforms in the 2020 time frame. CEOS believes that these will provide novel observing capabilities for operational polar satellites that complement the established and continuing microwave and thermal IR humidity soundings. The suite of complementary payloads on the Second Generation Polar System are expected to provide a sustained capability which could be complemented with specific research instrument missions. The Lightning Imager (LI) on MTG will provide new capability to detect deep convective cloud systems.

Although CEOS believes that this combination of missions will substantively address the requirements underpinning this recommendation, CEOS notes a possible gap in the area of operational multi-frequency radar - but this is under consideration by post-GPM system study being led by NASA and JAXA. CEOS would welcome dialogue with the GEO IGWCO on how to ensure the need is apparent to key decision-makers.

Proposed CEOS action for C.3: same as C.2

CEOS lead entity: P-VC

CEOS contributing entities:

Proposed external partnership: WMO, CGMS, IGWCO

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.

CEOS response:

Current GPM observations include GMI/AMSR-2, ATMS and SAPHIR plus the DMSP instruments and the recommendation has been already realized substantially. The CEOS Precipitation Virtual Constellation is coordinating the GPM constellation and its improvements in coverage and observation quality. The Precipitation Virtual Constellation is studying the post-GPM mission, including a three-frequency precipitation radar.

CEOS notes and supports that a number of missions are planned, or are under consideration. These missions include ATMS on J-1 and J-2, AMSR-2 follow-on on GCOM-W2, W-COM and two conical scanners and a cross-track MW sounder to be flown on EPS-SG.

CEOS notes that further study would be required, led by the GEO IGWCO, to determine how science and downstream user communities would benefit from having the 8-12 AMSR2/GMI type instruments in space, as proposed by this recommendation. The coverage of the tropics - thanks to low-inclined orbit missions - should be evaluated in detail, since (after the demise of TRMM) current capability is provided only by the SAPHIR sounder on board the Megha-Tropiques mission (already in extended life phase). Such a study should pay particular attention to anticipated downstream economic benefits, the cost of establishing the relevant space and ground segments, and clarification of the aspects of the water cycle that would be left under-observed. CEOS notes that there are positive synergies in enabling these study to be realized in cooperation with the WMO/CGMS International Precipitation Working Group.

CEOS will also conduct a study to consider the option of emulating the TRMM multi-satellite precipitation analysis (TMPA) system for soil moisture. Such an approach would involve multiple polar orbiting and geostationary satellites calibrated to the reference instrument(s) on a core soil moisture satellite mission. The possibility of increased spatial resolution (< 1km), as well as increased temporal resolution, may have greater relevance to agricultural production which is of high, and growing, policy relevance.

CEOS notes that the Soil Moisture Operational Products System (SMOPS) of NOAA combines soil moisture retrievals from multi-satellites/sensors to provide a global soil moisture map with more spatial and temporal coverage (http://www.ospo.noaa.gov/Products/land/smops/). CEOS supports the idea of having a

better sampling in spatial and temporal domains of soil moisture using passive microwave at low frequency on polar orbits.

CEOS notes that George Huffman/NASA plans to develop a white paper on precipitation and coordination with P-VC is on-going.

Proposed CEOS Action for C4: CEOS to participate in the development of the white paper on precipitation, which George Huffman/NASA will lead.

CEOS lead entity: P-VC

CEOS contributing entities: TBD

Proposed external partnership: WMO, CGMS, IPWG, IGWCO

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 of supply for these instruments.

CEOS response:

Precipitation Virtual Constellation is studying a post-GPM mission, including a three-frequency precipitation radar (Ku, Ka and W bands). In the study, a long-term strategy for the precipitation radar and precipitation mission will be developed. It is useful to note that the potential of assimilating SMOS/SMAP data in order to improve rainfall estimates derived from GPM series of satellites.

CEOS notes that issues of provision of satellite measurements on an operational basis is a question for individual Agencies and their governments, but that the ability to explain how a particular mission would form part of a coherent international satellite observing system is a powerful input to funding decisions. CEOS further notes that the successful application of data from non-operational programs to deliver results to influential users, and effective communication of the impact and relevance of those applications by those users to key decision-makers, is an important step in transitioning to an operational basis. This would be an area where CEOS welcomes the support of the GEO IGWCO in working with user communities. GEO support and GEO member commitments will be requested to ensure continuity of supply for these instruments.

Proposed CEOS action for C.5: same with C.4.

CEOS lead entity: P-VC (TBC)

CEOS contributing entities: TBD

Proposed external partnership: WMO, CGMS, IGWCO

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.

CEOS response:

Numerous CEOS members are actively engaged in the development and improvement of LST estimation methods and products. At high spatial resolution, NASA and USGS are supporting studies to exploit Landsat thermal data to produce calibrated LST for improved ET estimation. NASA is considering deployment of a Landsat-like thermal sensor (2019) to ensure continuity of such measurements. In a cooperative framework, CNES (with NASA/JPL, ISRO), is currently defining a high spatial resolution/high revisit mission (60m, 3 days) in the TIR dedicated to agricultural and natural ecosystems water stress, and to coastal and inland waters monitoring.

At moderate-to-low spatial, but higher temporal resolution, EUMETSAT provides LST information from Meteosat and Metop in near real time and NOAA operationally distributes real-time LST products from S-NPP VIIRS and GOES. Both organizations plan continued production of LST (e.g., from J-1, J-2, GOES-R and additional Metop missions).

And the status of JAXA GCOM-C with SGLI is “Approved” with plans to launch in 2016 or thereafter. ESA is developing advanced global LST algorithms that will provide 1km measurements with a daily geographical repeat rate when Sentinel-3a and b are in orbit in 2017/2018.

CEOS notes that research into new techniques for LST measurement, fusion of in-situ and multi-resolution satellite data and remote sensed ET estimation itself is needed before this recommendation can be fully realized. For example, greater leveraging of data from polar and geostationary satellites may yield higher spatial and temporal resolution products. LST data assimilation in process-based models may suggest different

approaches to measuring LST are needed to track ET. Furthermore, a greater focus on quality control, especially cloud screening, is required for geostationary LST observations.

A number of CEOS Agencies have expressed their commitment to research, develop and employ calibration and processing techniques that yield the highest quality LST observations allowed by system performance and available resources. Further, CEOS notes that the Land Surface Imaging Virtual Constellation has identified the coordination and optimization of LST contributions from CEOS Agencies in support of confirmed/ validated requirements for ET estimation as a key priority.

CEOS respectfully suggests that the demand for real-time provision of well-calibrated LST at fine spatial resolution (e.g., Landsat) should be carefully assessed, as meeting it would require significant and sustained additional investment.

CEOS notes that the GEO IGWCO should progress efforts to improve ground networks (in accordance with D.2) for cloud and atmospheric water vapour to ensure that there is confidence across users and governments that current, and proposed, satellite investment by CEOS Agencies are effective.

Proposed CEOS action for C.6: CEOS to coordinate its LST missions towards improved ET estimation.

CEOS lead entity: LSI-VC

CEOS contributing entities: WGCV (TBC)

Proposed external partnership: WMO, CGMS, GTOS

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. It 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.

CEOS response:

CEOS Agencies are supporting the next GRACE system, Grace follow-on (expected launch ~2017), which will demonstrate some improvements resulting from technological improvements as recommended.

CEOS suggests that the underlying issue is the need for better change detection of groundwater (or total water). Improved ranging from laser interferometry and moving to

a drag-free design would be helpful, and is being explored. However, factors to consider in the overall algorithmic approach, such as influences from atmospheric pressure and ocean circulation, and the need to couple the data with accurate estimates of snow, ice, soil moisture and vegetation water content, and CEOS will encourage Agencies to consider these in their longer-term plans. CEOS Agencies will require additional input from the user community, and additional resources, to study this issue comprehensively.

CEOS will require enhanced engagement from the relevant GEO initiatives and bodies to deliver on this.

Proposed CEOS action for C.7: This recommendation has been already implemented and no new CEOS action is required.

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.

CEOS response:

CEOS notes that supporting information in the GEOSS Water Strategy implies that this goal is aimed at freeze/thaw patterns, snow cover, snow water equivalent, and snow pack properties. CEOS notes that freeze-thaw aspects are addressed in the response to C.9.

CEOS is confident that this is being addressed. CEOS notes that Agencies have multiple satellites operational and planned to give information on snow cover and water equivalent, as well as to discern types of falling precipitation. Studies and field campaign activities are planned to further assess the capability of future satellite systems to improve observations of snow, in particular SWE, in more areas at enhanced spatial resolutions and with better accuracy.

Proposed CEOS action for C.8: The recommendation has been already addressed by CEOS Agencies and no new CEOS action is required.

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.

CEOS response:

CEOS notes the importance of understanding these patterns. Data from a range of current, planned, and considered CEOS missions and instruments, such as GCOM-C (vegetation conditions), SMOS, ASCAT, SMAP (surface freeze/thaw state), AirMOSS-P (Freeze/Thaw boundaries) and BIOMASS, AMSR-2, will support work in this area. CEOS further notes that CEOS Agencies have supported research in this area.

CEOS suggests that GEO IGWCO more clearly articulate the measurements required, which will help identify any specific gaps and opportunities in current and planned measurements including merging datasets (see E.1).

Proposed CEOS action for C.9: The recommendation has already been addressed by CEOS Agencies and no new CEOS action is required unless additional observation requirements are identified.

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.

CEOS response:

CEOS will undertake a high-level feasibility assessment of the benefits and technological difficulties of designing a hyperspectral satellite mission focused on inland, estuarine, deltaic and near coastal waters - as well as mapping macrophytes, macro-algae, seagrasses and coral reefs at significantly higher spatial resolution than 250m. CEOS notes that new information has emerged from the GEO Water Quality community in recent months suggesting that alternative approaches, involving augmenting designs of spaceborne sensors for terrestrial and ocean colour applications to allow improved inland, near coastal waters and benthic applications, could offer an alternative pathway to addressing the same underlying science questions. Accordingly, CEOS will also analyse the benefits and technological difficulties of this option as part of the high-level feasibility study.

CEOS will also examine the potential of establishing threshold and baseline observation requirements for sensors suitable for water quality applications. This information will inform CEOS Agencies when considering the potential to adapt their sensors to add this application area to their mission designs.

CEOS notes that funding for dedicated missions, or for enhancing or adapting mission designs, is a decision for individual Agencies and governments. CEOS recommends that the GEO Water community commence the process of defining inland and near-coastal and benthic habitat essential variables for water quality. CEOS recommends that this analysis should include a rigorous assessment of relative priority, linked to defined economic, social and environmental benefits. This information would be of great value in informing investment decisions.

Proposed CEOS action for C.10: CEOS to make a feasibility study on a hyperspectral satellite mission focused on water quality measurements.

CEOS lead entity: WSIST

CEOS contributing entities: LSI-VC (TBC), OCR-VC
Proposed external partnerships: GEM, GEO Task WA-01-C4 and WA-01 IGWCO, IOCCG

3 Strengthening in-situ data acquisitions

CEOS will, consistent with its mission and objectives, support organizations with leadership on in-situ observations to address the recommendations in this section.

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.

CEOS response:

CEOS supports the notion of continued support to such networks (many already established through CEOS Agencies and other activities under CGMS, WMO, etc.) but urges the operators to make the data available to the scientific community.

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; 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.

CEOS response:

CEOS notes its support for the development of a strong rationale for any Earth observation-enabled initiatives, and the importance of such a rationale in securing increased financial commitments. CEOS requests further coordinated efforts by the in-situ and space communities for the development of Standard Operation Procedures, network calibration best practices, etc. CEOS is willing to support this work on a best-efforts basis. It should be noted that soil moisture networks are useful only under specific conditions especially with respect to spatial and temporal coverage and harmonisation. Some efforts have been made (see ISMIN) but work remains to be done. Specific studies to quantify representativity are needed but one should note that the soil moisture missions did start addressing the issue in their Cal/Val programmes (SMOS and SMAP). Cosmic ray proves are very interesting and have a significant areal representativity (~800m) but correspond to variable significant depth and are affected by varying vegetation cover.
CEOS notes its contribution under C.4 in relation to satellite sensing of soil moisture, including GCOM-W2, SMOS Follow-on or W-COM, which are under consideration.

A joint programme leading to an operational soil moisture satellite product based on SMOS/SMAP track record seems a strong case to promote as it provides a global homogeneous and uniform set of soil moisture fields.

4 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.

CEOS response:

CEOS Agencies confirm that they are engaged in several R&D activities (some of which have led to operational products) that are paving the way for multi-sensor precipitation products. A wide range of techniques have been used to date, although the use of NWP model information is likely limited at this stage. Continued international coordination through various precipitation working groups (i.e., CGMS/IPWG and CEOS/P-VC) is encouraged, where many of the state-of-the-art techniques are discussed, intercompared, etc.

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.

CEOS response:

CEOS Agencies will continue to support programs with the aim of verifying and validating national forest and land cover change. A range of existing data types are under-used in characterising soil texture, and CEOS would encourage the GEO IGWCO to evaluate how existing data types (such as SAR) could be optimally used. CEOS notes that numerous activities exist across the world and those should be closely coordinated, in particular with the Global Terrestrial Observation System (GTOS) GOFC-GOLD panel (http://www.fao.org/gtos/gofc-gold/index.html).

CEOS notes that soil texture data are required for soil moisture retrieval algorithms, and that, without this information, the value of satellite soil moisture observations cannot be fully realised. Currently, the data used by the soil moisture and land surface modeling communities are from the datasets of Reynolds, Jackson and Rawls (1999, WRR) based on the FAO world soil map. CEOS notes there is significant opportunity to improve these and therefore improve soil moisture algorithms and/or land surface models.

CEOS notes the importance of generating improved the global soil texture map in order to improve modeling and retrieval of soil moisture and to coordinate development of integrated soil moisture products. CEOS will define its soil texture map requirements, and communicate them to IGWCO.

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

CEOS response:

CEOS notes that a range of existing, planned, and considered satellite missions provide datasets that could help provide the backbone for such an effort.

CEOS notes that for inland waters and coastal and coral reef areas with permanently water-covered areas, spectral inversion methods and stereo photogrammetric methods can be applied using high (< 30 m) and moderate (~ 30 m) resolution satellite imagery. CEOS further notes that for water bodies with temporarily exposed areas, rating curves and advanced statistics applied to long term mid- to high-spatial resolution archives can provide digital elevation models.

CEOS Agencies are also exploring techniques that mine the long time-series of moderate-resolution satellite data, using semi-analytical spectral inversion methods and advanced statistics, to develop DEMs and shallow-water bathymetry products at continental-scales with potential applicability to global scale. CEOS agrees that there is value in exploring opportunities to integrate all these different approaches to maximise the value of existing satellite data.

CEOS suggests that a global approach will require global agreement on the methodology to obtain a reliable consistent bathymetry product, requiring coordination among a range of stakeholders. CEOS would be willing to contribute to such an activity, if appropriately led and coordinated.

CEOS notes that there are GEO foundational activities to address this issue (TBC). CEOS will consider joining any external activities to define a methodology to develop global bathymetry of surface waters using satellite data.

E.8. The feasibility of establishing a monitoring system of man-made reservoirs should be developed. 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.

CEOS response:

A variety of groups within the remote sensing community have been researching methods to identify surface water bodies (including lakes and reservoirs) and monitor their areal extent over time. Efforts to estimate and monitor their volume require information on both

bathymetry (see recommendation E.7) and stage (i.e., water surface height). The capability to monitor stage reliably through satellite remote sensing is scale/resolution dependent. The planned NASA/CNES SWOT mission (estimated launch date 2020) will provide information on stage for lakes and reservoirs of sufficient size. Research on SWOT algorithm development, calibration and validation across a wide variety of environments and scales is being supported in the interim. Additional discussion of requirements and specification is necessary to address this and related recommendations. CEOS Agencies commit to participation in a GEOSS user/working group formulated to define a global framework for reservoir monitoring. Coordination of such CEOS involvement would be led by CNES.

USGS is investigating the use of Landsat to systematically monitor the extent of surface waters at high spatial resolution. While these measurements in themselves to not provide absolute information on storage, they can be used to index changes in storage conditions and, in combination with other satellite or in-situ data, can be used to estimate and monitor surface water in storage.

CEOS will consider participating in GEO activities to define a global framework for surface water storage monitoring.

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.

CEOS response:

CEOS Agencies have explored, and will continue to explore, combining GRACE information with other in-situ and satellite observations through data assimilation techniques and land surface modeling to produce enhanced groundwater assessments. Information will be made available to GEO and the water cycle community through peer reviewed publications on achieved capabilities and limitations of current approaches. It is thought that the enhanced assessment will have some utility for the water management community, albeit still limited due to the coarse nature of observations available from GRACE. CEOS will continue to explore combining GRACE information with in-situ observations as part of its routine activities.

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.

CEOS response:

CEOS notes that Agencies are considering missions/programs dedicated to advance the measurement of snow properties from space, and opportunities to generate a suite of snow products as part of their baseline programs. CEOS Agencies are also involved in dedicated field campaigns focussed on snow and ice to help validate satellite measurements.

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.

CEOS response:

CEOS notes that several CEOS Agencies are engaged in such activities, although coordination to date is limited to WMO's GCW program. Additionally, the WCRP CliC can be considered, although much like GCW, there is no coordination on this activity.

CEOS agencies are generating products in response to GCOS ECV's, including snow cover. If an initiative to develop a research-quality dataset of the climatology of snow properties is launched, CEOS will consider how it can support such an initiative. CEOS notes that the WGClimate is available as a contact point for information and advice on use of space data for monitoring snow cover.

5 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.

CEOS response:

CEOS is committed to improving the discoverability and accessibility of the data and products of its Agencies, and enhancing the application of data stewardship principles, within and across Agency programmes. These efforts are led by the Working Group on Information Systems and Services (WGISS), which has published a range of best practice guides linked to broader GEO activities and principles. This group is now working closely with Agencies to embed these best practice guides into internal systems, and has made significant progress through initiatives such as the IDN, FedEO and CWIC.

A number of CEOS Ad-hoc Teams, working with WGISS, are exploring next-generation architectures for the exploitation of very large volumes (multi-petabyte scale) of satellite data using advanced statistical techniques and high performance computing. Such architectures also have significant potential to enable the water community to better harness existing and future satellite missions, and combine satellite data with in-situ data, potentially delivering products based on existing or planned missions rather than requiring specific new satellites. Discussion with the GEO IGWCO on this issue would be welcome.

CEOS Virtual Constellations, and many individual CEOS Agencies, have protocols in place to reprocess datasets. CEOS acknowledges challenges of data reprocessing and its significant impact on resources. CEOS is open to discussions with the GEO IGWCO on opportunities to improve and better coordinate reprocessing protocols and campaigns. CEOS notes the importance of having clear provenance chains from the sensor to the end-user products for certain applications, particularly those feeding into regulatory processes.

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.

CEOS response:

CEOS notes that this recommendation is directed to GEO. CEOS will consider how to support this recommendation once GEO develops plans for infrastructure of data availability. CEOS does, however, refer again to its response to F.1 noting the potential for next-generation data architectures (where users go to the data rather than vice-versa) may be a key part of the solution to use of very large data sets.

CEOS notes that new approaches, such as cloud computing and the CEOS DataCube platform, offer significant potential to ameliorate the problems historically caused by low bandwidth. The ability to 'bring users to the data' should be fully explored and exploited, as it may be more feasible than building high-speed links capable of sustaining many Terabytes of data transfer a day. Moreover, in many cases, telecommunication link capacity is only one factor, with the ability to store, retrieve, process and analyse very large space datasets also lacking.

6 Expanding capacity development

CEOS will, consistent with its mission and objectives, support other organisations to address the recommendations in this section.

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.

CEOS response:

This recommendation is directed to GEO. CEOS Agencies will consider participation in planned GEO Capacity Building Workshops, as they are planned. CEOS, through its Working Group on Capacity Development and Data Democracy, is happy to contribute to the proposed GEO Water Strategy capacity-building workshops as part of core business.

7 Additional recommendations

Although not listed in the 22 recommendations CEOS may also wish to provide input on the following two recommendations that were cited later by the IGWCO CoP leader as having relevance for CEOS..

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 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.

CEOS response:

CEOS considers that identifying user requirements for Earth observation is one of the most critical tasks of GEO for SBA`s. CEOS will be willing to participate in discussion with GEO with regard to how a study of the methods for assessing the requirements and needs of users should be undertaken.

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.

CEOS response:

CEOS notes that this recommendation is already being progressed through the GEO Global Water Quality Community of Practice, with participation from a range of CEOS Agencies. CEOS notes that IOCCG is developing the IOCCG report on global water quality monitoring.

CEOS will consider its involvement when further information on the global water quality framework becomes available.

8 Way forward

To be effective, the coordination of the progress on the CEOS response to the GEOSS Water Strategy will require a sustained effort with regular and routine reporting to CEOS Plenary and/or SIT meetings – in the vein established by the CEOS efforts in relation to the GCOS Implementation Plan and the GEO Carbon Strategy. The GCOS effort enjoys the benefit of a clear and dedicated leadership for this coordination and reporting, in the shape of WGClimate. The corresponding leadership for execution of the Carbon strategy has been less clear and it continues to take time to determine leadership within CEOS for the coordination. The same challenge will apply to the coordination of the Water Strategy actions.

The response to action C.1 suggested that CEOS might establish a Virtual Constellation for measurements of the Water Cycle – for 'enhanced coordination of satellite missions, data acquisition and product generation to support an integrated approach to water monitoring'. And in due course, such a group, were it to be established, might constitute a logical entity for the stewardship of the CEOS Response to the GEOSS Water Strategy and its routine reporting to CEOS. But such a group does not yet exist – dependent on the conclusions of a proposed one-year feasibility study for the Constellation, and acceptance of these conclusions by CEOS.

To ensure continuity of effort, and to support implementation of the proposed feasibility study, it is proposed that the ad-hoc Water Strategy Implementation Study Team (WSIST) be extended for a period of one year by the CEOS Plenary in Kyoto. The Team will include consideration of stewardship of the response to the GEOSS Water Strategy actions in its efforts, as well as undertaking the job of reporting on progress during the year.