WMO SPACE PROGRAMME

Report to Plenary on item 3.7

REFERENCES:

Cg-XVI/Doc. 3.7, Cg-XVI/C/WP 3.7

APPENDICES:

A. Draft text for inclusion in the general summary on item 3.7
B. Draft Resolution 3.7/1 (Cg-XVI) - Development of an Architecture for Climate Monitoring from Space

ACTION PROPOSED:

It is recommended that the draft text given in Appendix A be included in the general summary of the work of the session and that the draft resolution in Appendix B be adopted.
3.7 WMO Space Programme (agenda item 3.7)

Meteorological Space-based Observing System

3.7.1 Congress reaffirmed the importance of integrated satellite systems as a unique source of observational data for monitoring of weather, climate and the environment. It stressed the importance of further advancing instrument intercalibration, data exchange, data management standardization, user information and training, in order to take full advantage of space-based capabilities in the context of the WMO Integrated Global Observing Systems (WIGOS).

3.7.2 It noted with appreciation that operational satellite coverage from the geostationary orbit was currently ensured by China (FY-2D and FY-2E), EUMETSAT (Meteosat-9, Meteosat-7), India (Kalpana and INSAT-3A), Japan (MTSAT-2), the Republic of Korea (COMS-1) and the United States of America (GOES-11, GOES-12, GOES-13); operational polar-orbiting coverage was ensured by China (FY-3A and FY-3B), EUMETSAT (METOP-A), and the United States of America (NOAA-18 and NOAA-19). Additional satellites were either in commissioning, such as the polar-orbiting Meteor-M1 and the geostationary Elektro-L N1 from the Russian Federation, or in back-up or secondary mode. Congress furthermore underlined the ocean surface topography monitoring by Jason-2 provided by EUMETSAT, France and the United States of America (USA). It also recalled the valuable contribution of satellite missions operated by Research and Development agencies of a number of WMO Members including China, France, Germany, India, Japan, the USA and the European Space Agency. Whether these missions are designed as technology demonstrators, or as support to scientific investigations, their data are increasingly used in support of operational meteorological activities and climate monitoring. Congress encouraged the operators of these satellites to maximize the availability of data to Members. Congress emphasized the value of scatterometer wind data products which have become essential to tropical cyclone monitoring.

3.7.3 Congress was informed that new geostationary spacecraft series were planned to be implemented in the 2014-2017 time frame by several satellite operators. It encouraged the relevant regional associations, in collaboration with satellite operators, to prepare the user communities to take advantage of these enhanced capabilities in order to avoid any disruption for operations. It recalled that the CBS had recommended that Members implementing new satellite generations include an appropriate overlap period between current and future systems to facilitate data intercomparison, product validation, and smooth transition into operations.

3.7.4 Bearing in mind that satellite soundings from low-Earth orbits are a crucial input to NWP, Congress expressed concerns that there were no plans towards implementing a sounding mission on an early morning orbit (Equatorial Crossing Time around 5:30) as required in the Vision for the GOS in 2025. It encouraged satellite operators to consider optimizing the orbital distribution of future missions to alleviate this gap.

3.7.5 Congress highlighted that Highly Elliptical Orbit (HEO) missions have the potential to complement geostationary imaging and Space Weather monitoring capabilities to provide quasi-permanent observations over Polar Regions and encouraged Canada and the Russian Federation in their plans to demonstrate the operational benefit of such missions.

Data Accessibility and User Training

3.7.6 Congress stressed the need for improved accessibility of satellite data and products, particularly in developing countries, and welcomed the recommendation from CBS-Ext.(10) to consider among its priorities: (a) to organize the formulation of data requirements and the dialogue
between data users and providers; (b) to implement sustainable regional Digital Video Broadcasting by Satellite (DVB-S and DVB-S2) dissemination systems (such as IGDDS or GEONETCast) offering cost efficient access to satellite data and products in every region; (c) to integrate all relevant data types in such broadcast services, including inter-regionally exchanged data; and (d) to support harmonization of future Direct Broadcast Systems as well as complementary data access and distribution services via the Internet, recognizing the different user needs. Congress welcomed the setting up of regional expert groups in RA I, RA III, RA IV and RA V to review the requirements for satellite data access as well as the Pilot Project in RA II aiming to enhance accessibility of satellite data in the Region.

3.7.7 Congress welcomed the expansion of the Virtual Laboratory for Education and Training in Satellite Meteorology (VLab) that included 12 Centres of Excellence (located in Argentina, Australia, Barbados, Brazil, China, Costa Rica, Kenya, Niger, Oman, Republic of Korea, Russian Federation and South Africa) sponsored by satellite operators (CMA, CONAE, EUMETSAT, IMD, INPE, JMA, KMA, NOAA, and ROSHYDROMET) which allowed organizing satellite training in all WMO Regions and all WMO official languages. It welcomed the VLab widening its scope and audience through partnerships with other training-related initiatives such as the COMET Programme of the USA. Congress recalled the usefulness of regional conferences (such as the EUMETSAT Meteorological Satellite Conferences, the GOES Users and Direct Readout conferences, and the recent Asia-Oceania Meteorological Satellite Users Conference) to raise user awareness on satellite systems and their utilization. It encouraged satellite operators to further organize such events and facilitate participation of WMO Members. It commended China, Japan and the Republic of Korea for their decision to jointly sponsor and rotate hosting future Asia-Oceania Meteorological Satellite Users Conferences.

3.7.8 Congress welcomed the setting-up of the Sustained Coordinated Processing for Environmental Satellite Data for Climate Monitoring (SCOPE-CM) and expected that this initiative would soon reach an operational stage and be expanded. It invited the Space Programme to consider similar initiatives to coordinate the delivery of satellite derived products responding to the requirements of other application areas including severe weather forecasting, precipitation estimation, or volcanic ash detection. Congress welcomed the orientation taken by the Commission for Climatology (CCl) to further incorporate satellite products in climate monitoring and its plan for enhancing linkages with the Space Programme and the SCOPE-CM initiative. It expected that this collaboration would bring substantial benefits to WMO global and regional climate monitoring activities. It recommended using existing mechanisms such as workshops, seminars or expert meetings coordinated by the CCl or within SCOPE-CM to address gaps in satellite-derived products for use in the WMO Climate System Monitoring (WMO-CSM).

Architecture for climate monitoring from space

3.7.9 Noting the request from EC-LXII, Congress agreed that an architecture for sustained climate monitoring from space should be defined and implemented, based on the requirements established by the Global Climate Observing System (GCOS) for the Essential Climate Variables (ECVs) that can be monitored from space. It welcomed the effort initiated to formulate a concept for such an architecture as included in the Annex to draft Resolution 3.7/1 (Cg-XVI), noting that the architecture should enhance, and be modelled after, the system which has been developed for weather monitoring and forecasting over the last fifty years, to the extent possible. Congress further noted the importance of enhancing synergies between in-situ and space-based observing systems, and recommended that this be taken into account in the development of the architecture. Specifically with regard to ocean observations, it recognized the potential importance of the existing JCOMM Observing Programme Support Centre (JCOMMOPS) to provide some coordination mechanism, and to the enhancement of such synergies.
3.7.10 Congress agreed that such architecture should be defined as an end-to-end system, involving the different stakeholders including operational satellite operators and R&D space agencies, the Coordination Group for Meteorological Satellites (CGMS), the Committee on Earth Observation Satellites (CEOS), the Global Climate Observing System (GCOS), the World Climate Research Programme (WCRP) and the Group on Earth Observations (GEO). Within the WMO context, the architecture shall be part of the space-based component of WIGOS. Other components of this end-to-end system would include the intercalibration activities of the Global Space-based Inter-Calibration System (GSICS), additional calibration and validation activities to be conducted in coordination with the Commission for Instruments and Methods of Observation (CIMO), the product generation efforts as done within the SCOPE-CM and the training and capacity building activities of the VLab. Congress therefore adopted Resolution 3.7/1 (Cg-XVI).

Space Weather

3.7.11 Congress noted with appreciation that the Inter-Programme Coordination Team for Space Weather (ICTSW) involved experts nominated by 13 WMO Members and six international organizations, and had adopted an initial work plan focusing in priority on the review of Space Weather observing requirements and data management standardization issues, in consultation with relevant CBS expert groups. It encouraged Members to provide extrabudgetary financial and staff resources to support this coordination activity, given the severe impact of Space Weather on observation and telecommunication infrastructure and on aviation safety, as well as the potential synergy between Space Weather warnings and meteorological service delivery. Congress noted the outcome of a Side Event on Space Weather, as summarized in the Annex to this paragraph. It noted that a coordinated effort by Members is needed to address the observing and service requirements to protect against the global hazards of Space Weather. It invited the WMO Space Programme, in coordination with the Inter-programme Coordination Team on Space Weather and with the support of the relevant technical commissions, to develop near-term and far-term action plans, including education and training, and work with the WMO Regional Associations to implement a coordinated strategy for Space Weather.

Radio Frequency Coordination

3.7.12 Congress appreciated the substantial efforts made by Members in protecting the radio frequency bands allocated to meteorological systems and environmental satellites. It urged all Members to ensure continuous coordination with their national radio communication authorities, and to participate actively in national, regional, and international activities involving radio communication regulatory issues for the defence of radio frequency bands for meteorological and environmental activities. It also supported the Council’s request to the Secretary-General to give priority to this subject. Congress also noted with appreciation the effective work of the CBS Steering Group on Radio Frequency Coordination (SG-RFC) in addressing radio frequency issues of concern to the Space Programme, and the need to maintain this effort at a high level.

Consultative Meetings

3.7.13 Congress noted that the Consultative Meetings on High-level Policy in Satellite Matters (CM) had convened during the Congress time frame, as recommended by the Executive Council, and took due note of the outcome of this meeting. Congress expressed its high appreciation to Dr A.I. Bedritskiy who has provided outstanding leadership as Chairman of CM over the past eight years. It reaffirmed the importance of having the CM chaired at the highest level of the Organization. Congress thanked Germany and Japan for seconding staff resources to the Space Programme, EUMETSAT, and NASA for its contribution to the Space Programme Trust Fund.

3.7.14 Congress agreed with the Space Programme description as provided in the Annex to this paragraph.
Annex to paragraph 3.7.11 of the general summary

GLOBAL PREPAREDNESS FOR SPACE WEATHER HAZARDS

The participants in the Cg-XVI Side Event on Space Weather acknowledged:

- The increasing risks of Space Weather events to all WMO Members due to the increasing reliance on advanced technologies;
- The diversity of sectors impacted by Space Weather, including: navigation, communication, electric power, pipelines, satellites, and aviation, as well as the impacts on core meteorological observations;
- The actions being taken today by industries and governments to prepare for, and respond to, Space Weather storms and related indirect hazards;
- The progress already achieved in establishing ground-based and space-based observing networks;
- The progress already achieved in establishing a framework of Space Weather prediction and service centres;
- The need for coordinated near-term and far-term actions in order to plan and implement capabilities that will meet regional and global Space Weather requirements, as identified in the WMO Rolling Review of Requirements (RRR) in a sustained, comprehensive, robust, efficient and integrated fashion;
- The capacity of WMO Members to contribute to a globally coordinated system of observations and services, relying on their national R&D and operational assets, as well as on international partnerships;
- The benefits that can accrue to all WMO Members from increased WMO coordination of Space Weather activities;
- The need to raise awareness, advocate the benefits, and provide training so that WMO Members can take advantage of coordinated Space Weather activities.

The participants in the Cg-XVI Side Event on Space Weather therefore recommended:

- To develop and implement near-term and far-term action plans that will enable Members to determine needs and requirements, and to benefit from existing services;
- That WMO Members will contribute, where possible, to enhance regional and global capabilities, including observation collection and information delivery;
- To strengthen the statements included in paragraph 3.7.11 of Document 3.7 for the WMO Space Programme along the following lines: “The Congress noted that a coordinated effort by Members is needed to address the observing and service requirements to protect against the global hazards of Space Weather. It invited the WMO Space Programme, in coordination with the Inter-programme Coordination Team on Space Weather and with the support of the relevant technical commissions, to develop near-term and far-term action plans, including training and education, and work with the WMO Regional Associations to implement a coordinated strategy for Space Weather.”
Annex to paragraph 3.7.14 of the general summary

WMO SPACE PROGRAMME DESCRIPTION

1. **Overall objective and scope**

   The overall objective of the WMO Space Programme (WMO SP) is to promote wide availability and utilization of satellite data and products for weather, climate, water and related applications of WMO Members.

   Its scope is to coordinate environmental satellite matters and activities throughout all WMO Programmes; to give guidance to these programmes on the potential of remote-sensing techniques in meteorology, hydrology and related disciplines and applications; and to ensure effective cooperation with and among international partners and organizations dealing with satellite systems.

2. **Programme structure**

   The WMO SP has four main components:

   (a) Integrated space-based observing system;

   (b) Availability and use of satellite data and products;

   (c) Information and training;

   (d) Space Weather coordination.

3. **Programme governance**

   The lead technical responsibility for the WMO SP is assigned to CBS. The WMO Consultative Meetings on High-level Policy on Satellite Matters (CM) maintain a broad policy overview of the Programme.

   Space Weather activities are jointly overseen by CBS and CAeM.

4. **Programme activities**

4.1 **Integrated Space-based Observing System**

   **Long-term objective**

   The long-term objective is to develop an integrated space-based observing system involving operational and R&D environmental satellites and their associated ground segments. This observing system should support the WWW, as the space-based component of its GOS; and ultimately all the other WMO Programmes and WMO-supported programmes, as the space-based component of WMO Integrated Global Observing Systems (WIGOS).

   **Activities**

   The space components of the various observing systems are reviewed, and the gaps with respect to requirements are analyzed, in order to optimize the effectiveness of each component while striving for cross-cutting integration in the context of WIGOS.
WMO SP leads the revision of the baseline for the space-based observing system to achieve full implementation of the “Vision for the GOS in 2025”. It promotes intercalibration of satellite instruments and harmonization of their specifications. It encourages operational and R&D space agencies to contribute to the GOS and pursue system harmonization with best practices.

The transition of mature research systems to operational status is encouraged when appropriate, with a view to improve operational capabilities in line with evolving requirements, while ensuring the long-term sustainability required for operational applications and climate monitoring.

4.2 Availability and use of satellite data and products

Long-term objective

In view of the exponential increase in satellite data which is anticipated from upcoming satellite systems, a major challenge for the WMO SP in the next decade is to make these improved data and derived products available while increasing the number and geographical spread of users.

The objective is to enhance timely accessibility of satellite data and products as required by users in all WMO Regions, in particular in developing countries, to promote data interoperability through WMO Information System (WIS) standards and practices, and to stimulate coordinated processing of observations to derived products with traceable quality.

Activities

The WMO SP serves as a catalyst for improving dissemination and exchange of satellite observation data and products, and for standardizing data and metadata management consistent with WIS practices.

The Integrated Global Data Dissemination Service (IGDDS) project focuses on: (i) establishing regional requirements for access to data and products; (ii) implementing sustainable regional Digital Video Broadcast by Satellite (DVB-S) dissemination systems offering cost efficient access to satellite data in every region; (iii) integrating all relevant data types in such broadcast services, including inter-regionally exchanged data; and (iv) supporting harmonization of future Direct Broadcast systems as well as complementary data access and distribution services via the Internet, recognizing different user needs.

Building on international science groups and projects, the WMO SP stimulates the coordinated processing of satellite data to products, and the traceable quality of these data and products. Particular attention is given to climate applications, e.g. through the Sustained Coordinated Processing of Environmental Satellite Data for Climate Monitoring (SCOPE-CM) and to Disaster Risk Reduction.

Cooperation is encouraged to develop common basic tools for utilization of remote-sensing data, and on the assimilation of R&D and new operational data streams in NWP systems and climate models.

4.3 Information and Training

Long-term objective

The long-term objective is to raise awareness on satellite capabilities and promote satellite-related education to keep Members’ operational and scientific staff up to date with the latest technological innovations, with a focus on developing countries.
Activities

The WMO SP implements the Five-year Strategy for the Virtual Laboratory for Training and Education in Satellite Meteorology and Environmental Applications (VLab), relying on the network of Centres of Excellence sponsored by satellite operators. Close links are maintained with relevant national and international education and training initiatives.

WMO SP ensures that appropriate websites and portals provide guidance on the availability and usability of satellite data, products and services. Information material is to be provided, and translated into the official WMO languages as resources allow. Participation of WMO Members from developing countries in satellite users’ conferences is encouraged.

4.4 Space Weather coordination

Long-term objective

The long-term objective is to support international operational coordination for Space Weather, which has a severe impact on space assets and relies to a large extent on space-borne observations, and improve Space Weather warnings to major application areas including aviation.

Activities

Within available resources, through the Inter-Programme Coordination Team on Space Weather (ICTSW), the WMO SP supports coordination activities focussing on:

(a) Standardization and enhancement of Space Weather data exchange and delivery through the WIS;

(b) Harmonized definition of end-products and services, including e.g. quality assurance guidelines and emergency warning procedures, in interaction with aviation and other major application sectors;

(c) Integration of Space Weather observations, through review of space- and surface-based observation requirements, harmonization of sensor specifications, monitoring plans for Space Weather observation;

(d) Encouraging the dialogue between the research and operational Space Weather communities.

5. Coordination and partnership

WMO SP is conducted in partnership with space agencies of WMO Members and their coordination bodies: the Coordination Group for Meteorological Satellites (CGMS) and the Committee on Earth Observation Satellites (CEOS).

Participation in the WMO Consultative Meetings on High-level Policy on Satellite Matters (CM) provides space agencies with visibility on the WMO SP and related WMO strategy and expectations.

Through the WMO SP, WMO actively participates in CGMS, the main technical coordination body of space agencies for operational missions for weather or climate on such matters as orbit coordination, contingency planning, data dissemination formats, or data collection services. WMO
and CGMS have jointly initiated and are supporting a number of projects (related, for example, to satellite calibration, data dissemination, product generation, or training).

The WMO SP represents WMO as an Associate of CEOS, and interacts with its relevant entities such as the Working Group on Calibration and Validation, and the CEOS Working Group on Climate. Some WMO SP activities, such as maintaining the Dossier on the Space-based GOS, are conducted in collaboration with CEOS.

WMO SP supports expert groups that play a key role in providing expert advice and feedback, and stimulating developments within the user community. These groups include the International Winds Working Group, the International TOVS Working Group, the International Precipitation Working Group, the International Radio-occultation Working Group, and the Space Frequency Coordination Group.

Through its participation in international bodies, WMO SP promotes an integrated, global, space-based observing system, encourages cooperation whilst discouraging unnecessary duplication.


DRAFT RESOLUTION

Res. 3.7/1 (Cg-XVI) - DEVELOPMENT OF AN ARCHITECTURE FOR CLIMATE MONITORING FROM SPACE

THE CONGRESS,

Noting:

(1) Article 2 of the Convention of the World Meteorological Organization,

(2) Resolution 5 (Cg XIV) - WMO Space Programme,

(3) Resolution 30 (Cg-XV) - Towards enhanced integration between WMO observing systems,

(4) Paragraph 9.2.5 of the Abridged Final Report with Resolutions of the Fifteenth World Meteorological Congress (WMO-No. 1026) reaffirming the Executive Council decisions to provide full support for the GEO process and resulting GEOSS and to support its implementation to the maximum extent possible within the WMO mandate,

(5) Draft Resolution 3.1.1/1 (Cg-XVI) - Global Observing System,

(6) Draft Resolution 11.1/x (Cg-XVI) - Global Framework for Climate Services,

Considering:

(1) The benefits that have been achieved through the coordinated, collaborative and cost-effective approach to the planning and operation of an end-to-end system for weather observations, modelling, analysis and forecasting,

(2) The increasingly important role that space-based observations are playing in the long-term monitoring of the Earth’s environment,

(3) The substantial investment that Members have made in Earth-observation satellites to monitor and study weather, water, climate and related natural disasters,

(4) The importance of long-term, sustained and coordinated observations of the Earth’s climate, climate change and variability for the world's population, and particularly those at most risk,

(5) The benefits in efficiency, sustainability and cost-effectiveness that could be achieved through increased coordination of efforts among all parties involved in the planning and implementation of space-based observational capabilities and related operational processing activities for climate monitoring,

(6) The underpinning role that observations will play in the Global Framework of Climate Services (GFCS),

(7) The importance of integration of ground-based and space-based observations in the successful implementation of the WMO Integrated Global Observing System (WIGOS),
Appreciating:

(1) The important contributions Members, their satellite operators, international partner organizations and programmes make toward observing, and coordinating observations of the Earth from space,

(2) The relevant work undertaken by the Global Climate Observing System (GCOS) to identify the requirements associated with the Essential Climate Variables (ECVs) for the long-term and sustained observation of the Earth’s climate system,

(3) The invitation made by the sixty-second session of the Executive Council to the WMO Space Programme, in coordination with GCOS and with the support of relevant technical commissions, to work with space agencies, the Coordination Group for Meteorological Satellites (CGMS), the Committee on Earth Observation Satellites (CEOS), and the Group on Earth Observations (GEO) in order to develop an architecture for sustained, space-based climate monitoring as a component of the future WIGOS and GFCS, for consideration by the Congress,

(4) The early work done by the WMO Space Programme to develop a concept and initiate a dialogue among interested parties for an architecture for climate monitoring from space,

Recognizing:

(1) The WMO Space Programme provides Members with an appropriate framework to advance, in partnership with CEOS, CGMS, GCOS, GEO, the World Climate Research Programme (WCRP) and other partner organizations the development of an architecture for climate monitoring from space,

(2) The end-to-end system implemented by Members to support weather monitoring and forecasting, which includes the review of observational requirements, satellite observations, intercalibration, as well as product generation and training and user-engagement, can be leveraged for climate monitoring,

(3) The different, but complementary roles and responsibilities, of satellite operators and their coordinating mechanisms for activities which cover the spectrum of research and development and operational missions,

(4) That, in this architecture, space-based observations have to be supported by surface-based observations,

Decides that an architecture be developed using as a starting point the concept given in the annex to this resolution to provide a framework for the sustained and coordinated monitoring of the Earth’s climate from space;

Decides further:

(1) That the development be undertaken as a major initiative of the WMO Space Programme, as an important component of WIGOS, with the support of relevant technical commissions, and in coordination with satellite operators, CEOS, CGMS, GCOS, GEO and WCRP;

(2) That the results will be made available for the deliberations and final approval by the Executive Council;
Requests:

1. The Executive Council to monitor, guide, support and consider approving, at its sixty-fourth session, the development of an architecture for climate monitoring from space;

2. Technical commissions to:
   a. Guide the technical aspects of the development activities;
   b. Update WMO Regulatory Material, including development of the Manual on WIGOS;
   c. Provide the technical lead for the architecture through the Commission for Basic Systems (CBS), the Commission for Instruments and Methods of Observation (CIMO), and the Commission for Climatology (CCI);

3. Members to:
   a. Provide experts to participate in the development, implementation and operation of an architecture for climate monitoring from space;
   b. Provide voluntary contributions to the WMO Space Programme Trust Fund for the further advancement of the architecture development efforts;
   c. Share relevant experience and cooperate with one another in leveraging the existing end-to-end weather monitoring system to serve climate monitoring needs;
   d. Continue to enhance and integrate their national climate monitoring capabilities;

4. Regional associations to support and coordinate efforts of Members in the development and eventual implementation of an architecture for climate monitoring;

5. The Secretary-General to:
   a. Ensure management and support of the architecture for climate monitoring from space development efforts;
   b. Support the review and update of WMO Regulatory Material, including the development of the Manual on WIGOS;

Invites CEOS, CGMS, GCOS, GEO and WCRP to collaborate with the WMO Space Programme on the development of an architecture for climate monitoring from space.

Annex: 1
1. Introduction

The purpose of this document is to provide a basis for consultation and, ultimately agreement, on processes and capabilities to be implemented or maintained, and activities to be pursued, in order to monitor climate from space in a globally coordinated and efficient framework.

Section 2 recalls the motivation for such an architecture.
Section 3 describes key building blocks of the architecture in an end-to-end approach.
Sections 4 to 8 describe the contents of each component.
Section 9 suggests roles and responsibilities to lead this process.

2. Motivation

Facing the need to know and understand the evolution of climate in order to alleviate or prepare for its impact, e.g. for programmes like the Global Framework for Climate Services (GFCS), monitoring climate variables is a prerequisite, and space-based observation has an essential role in this respect.

Meteorological satellites have considerably evolved over the past fifty years and are now used for a variety of applications that span time scales from nowcasting to climate prediction, and include land, ocean, atmosphere and environmental applications. Instruments on research satellites have laid the groundwork for the development of operational satellite systems and resultant environmental applications are growing vigorously.

Specific climate payloads have been flown with success by both operational and research agencies over the last several decades. Operational meteorological missions are enhanced with some climate monitoring instruments, for example for Earth Radiation Budget or ozone monitoring. In response to the Global Climate Observing System (GCOS) Implementation Plan and its Satellite Supplement, the Committee on Earth Observation Satellites (CEOS) presented a comprehensive assessment of satellite capabilities for selected Essential Climate Variables (ECVs). There remain, however, challenges regarding the sustainability and/or continuity of selected missions and measurements to provide a continuous, long-term record of climate.

Responding to these challenges requires defining and implementing an architecture through a mechanism that accounts for the different roles and responsibilities of the respective entities while responding to the essential need for continuous and sustained operation. Given the important contribution of R&D programmes to climate observation, compounded with the increasing convergence of operational and research activities, the future space-based observing system has to rely on a strong partnership between research and operational entities.

3. A structured approach

3.1 Functional components

Taking as a starting point the requirements expressed by GCOS, and possible additional requirements in the future, the following functional components are considered:

- Analysis of user requirements;
• Observing capabilities;
• Essential Climate Variable (ECV) product generation and analysis;
• Data management, access and dissemination;
• User interface;
• Coordination and governance.

Figure 1: Key components of an end-to-end architecture

3.2 Cross-cutting considerations

The present concept document stays deliberately at high-level, since the detailed design will be developed at a later stage and should be evolving. The architecture should be defined in a long-term perspective. Building on existing assets, and taking into account the currently existing or planned capabilities, it should highlight the incremental effort needed.

In its concept, it should acknowledge:

• The evolving science and the need to ensure linkage with the science community;
• The evolving technology, avoiding being bound to current technical approaches;
• A Research-and-Operations (R&O) process, to be integrated in the evolving architecture.

The architecture should recognize and build upon the leadership exerted by CEOS, the Coordination Group for Meteorological Satellites (CGMS), the Group on Earth Observations (GEO), and the WMO Space Programme. Noting the necessary balance between best-effort and commitment, agreement should be sought on a process, supported by an implementation plan.
The development process should be responsive to evolving user needs. Robustness of systems and processes are necessary to support sustained acquisition and processing of mature observations and products. Quality assurance should be an integral part of each sub-system.

4. **User requirements analysis component**

4.1 **Input**

User requirements for observations are expressed by representative user communities, and kept under regular review following well established processes (GCOS Implementation Plan and Satellite Supplement, Rolling Review of Requirements (RRR)).

The requirements address geophysical variables (e.g. ECVs) rather than value-added products. Requirements are not for specific instruments either; they are in principle technology-free, thus not limited to space-based observation. Requirements should specify: variables, units, resolution (space and time), accuracy, continuity. They are consolidated in a database maintained by WMO and linked to the CEOS Missions, Instruments and Measurements (MIM) database.

The GCOS Implementation Plan reflects the needs of the United Nations Framework Convention on Climate Change (UNFCCC). Additional observational requirements for climate monitoring, however, may be driven by the WMO Climate System Monitoring and by climate applications for mitigation and adaptation purposes in the context of GFCS (e.g. for downscaling). The World Climate Research Programme (WCRP) requirements may also provide a relevant input.

4.2 **Requirements analysis**

An analysis is needed to select the subset of requirements that can be addressed from space, compare the requirements with the inventory of existing/planned observation capabilities, and perform a Gap Analysis.

5. **Observation capabilities component**

A comprehensive architecture should encompass operational capabilities and research or demonstration capabilities. In addition to these research and operational capabilities, a process should also be defined to facilitate transition from research to operational status when appropriate, and also recognize both research and operational activities are essential. Quality assurance should be inherent to these elements.

5.1 **Operational capabilities**

Operational status is understood as offering a clear long-term continuity perspective, which entails the in-principle commitment that the capability, or an equivalent one, will be maintained, enabling to serve an operational community in a sustained manner.

Operational missions should address all ECVs including atmosphere, ocean, land, and cryosphere, to the extent there are mature observation capabilities. They should follow the GCOS Climate Monitoring Principles for satellite observations. An important feature is mission robustness, which may imply provisions for relaunch, contingency planning, and overlap between consecutive missions when appropriate.

CGMS is providing technical coordination of operational programmes. The current baseline agreed by CGMS defines committed elements in geostationary and low-Earth orbit. An evolution of the CGMS baseline is underway to better serve climate monitoring, guided by the WMO Vision for the Global Observing System (GOS) in 2025. The baseline for the space-based observing system can
be described in terms of actual constellations (sets of satellites with coordinated orbits), or in terms of virtual constellations (sets of instruments distributed on different satellites but supporting similar missions) mapped with the ECVs. The future CGMS baseline, detailing missions, orbits and assignments, should ultimately be the foundation of the space-based component of the WMO Integrated Global Observing System (WIGOS).

5.2 Research and demonstration capabilities

R&D missions are twofold: missions for climate research (atmospheric/climate process studies) and missions for technology demonstration. By definition, R&D missions are not bound to any firm perspective of continuity. Research missions respond to a science plan developed in consultation with the climate community.

Space agencies have developed plans at the national level or in international partnerships. CEOS is leading a coordinated response on behalf of space agencies to climate needs, and has implemented several Virtual Constellations mapped with selected ECVs.

5.3 Transition process

Attention is required to avoid misunderstanding of the “Research to Operations” paradigm.

Research and operations are equally important to successfully deliver climate-related measurements. An operational follow-on should be considered for capabilities that have been successfully demonstrated from the point of view of performance, reliability, affordability, maturity, user uptake, and societal benefit. This does not prejudge any transfer of tasks or budgets among entities, which is an internal matter for each agency or country. Joint ventures among R&D and operational entities are strongly encouraged.

The goal is that parties are ultimately in a position to make long-term commitment. The appropriate level for a long-term commitment may be the national government (e.g. WMO Member through its Permanent Representative) since an individual agency may not have the mandate to commit beyond a programme life cycle or a budget cycle.

5.4 Quality assurance: calibration/intercalibration

Quality assurance considerations are applicable to all observation components (See the Quality Assurance Framework for Earth Observation (QA4EO)). The aim should be to generate Fundamental Climate Data Records (FCDRs). This shall build on:

- Global Space-based Inter-Calibration System (GSICS) involving CMA, CNES, EUMETSAT, ISRO, JAXA, JMA, KMA, NASA, NIST, NOAA, ROSHYDROMET;
- CEOS Working Group on Calibration Validation (including Cal/Val sites);
- GCOS Reference Upper-Air Network (GRUAN) and national initiatives such as the ARM (USA), SADE (France) etc. may support this activity;
- WMO-BIPM collaboration plans addressing measurement challenges in observations for climate monitoring (see proceedings of the first WMO-BIPM workshop, Geneva, 30 March-1 April 2010, WMO/TD-No. 1557).

6. ECV product generation and analysis component

The goal is to ensure sustained provision of validated and quality-controlled ECV products (Thematic Data Records). A number of initiatives are currently contributing to that goal, including:
• Sustained Coordinated Processing of Environmental Satellite Data for Climate Monitoring (SCOPE-CM);
• Climate Change Initiative (CCI) of the European Space Agency;
• World Data Centres (e.g. GAW DLR Data Centre on Aerosols).

These initiatives, however, are not addressing all the ECVs. There is a need for maintaining a mapping of the available/planned production of ECV products as well as “Additional Climate Variables (ACVs) if required.

For established, peer review validated products, production should be ensured in a sustained mode and quality controlled. New products shall be developed to fill gaps on priority needs, with a process for transitioning to a sustained mode according to their maturity, as assessed by a maturity index. Plans should be made for reprocessing. These products are inputs for climate monitoring analyses as part of, for example, the WMO Annual Statement of the Global Climate or the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports.

7. Data management, access and dissemination component

The scope is to ensure timely accessibility of observations and products in compliance with agreed interoperability standards.

Metadata, catalogue interfacing, and formats should be standardized in compliance with the Global Earth Observation System of Systems (GEOSS) interoperability standards (e.g. the WMO Information System (WIS) standards for WMO Members). Data should be properly catalogued and openly retrievable from data centres. In addition, acknowledging dual use of many data for both climate applications and real-time services, active data distribution should also be considered in accordance with standard practices and protocols (e.g. Direct Readout or rebroadcast).

8. User interface component

User interface should be maintained in order to seek feedback, monitor deliverables and compare with user requirements. Linkages shall be maintained in particular with the science community, the WMO Climate System Monitoring, climate assessment and climate prediction, and the GEOSS user community. Provisions shall be made to support user uptake, through capacity building including training. The annual WMO Statements on the Status of the Global Climate are an example of operational deliverables to the WMO Members, UN agencies and the general public.

9. Coordination functions

At the level of each component, coordination is needed. Tentative leads are suggested below for the respective components:

<table>
<thead>
<tr>
<th>Function</th>
<th>Suggested WMO involvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirement identification</td>
<td>GCOS and WCRP</td>
</tr>
<tr>
<td>User requirements analysis</td>
<td>(To be determined, involving CBS)</td>
</tr>
<tr>
<td>Observation capabilities</td>
<td>CGMS, GSICS, and CBS and CIMO Working Groups</td>
</tr>
<tr>
<td>ECV Product generation</td>
<td>SCOPE-CM</td>
</tr>
<tr>
<td>Data Dissemination and Access</td>
<td>(To be determined, involving CBS and WIS)</td>
</tr>
<tr>
<td>User Interface</td>
<td>GCOS, WCRP, and GFCS</td>
</tr>
</tbody>
</table>
An overall governance mechanism will be needed in order to:

- Manage evolution of the plan and maintain a long-term Vision;
- Monitor the commitments of each contributor, ensuring a smooth interaction among components;
- Maintain a proper link with GEO/GEOSS, support communication, outreach, and provide visibility to this collaborative endeavour.

### Document Change Record

<table>
<thead>
<tr>
<th>Version</th>
<th>Date</th>
<th>Description</th>
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<tr>
<td>Draft Outline 1</td>
<td>14 October 2010</td>
<td>Update for CBS-Ext.(10)/Doc. 4.2(3) discussion</td>
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<tr>
<td>Draft Outline 2</td>
<td>15 October 2010</td>
<td>Creation of document for CGMS discussion as CGMS WMO-WP-09</td>
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<tr>
<td>Draft Outline 3</td>
<td>6 December 2010</td>
<td>Update for CEOS discussion</td>
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<td>Version 1</td>
<td>20 December 2010</td>
<td>Creation report for WMO/GCOS Workshop discussion</td>
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<tr>
<td>Version 1.1</td>
<td>March 2011</td>
<td>Update for Cg-XVI/Doc. 3.7 discussion</td>
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