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Subsidiary Body for Scientific and Technological Advice
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Item 7 of the provisional agenda
Research and systematic observation

Update on progress made by space agencies involved in global observations in their coordinated response to relevant needs of the Global Climate Observing System and the Convention

Submission from the Committee on Earth Observation Satellites

1. The Conference of the Parties, by decision 9/CP.15, encouraged the Committee on Earth Observation Satellites (CEOS) to continue coordinating and supporting the implementation of the satellite component of the Global Climate Observing System (GCOS).

2. At its thirty-third session,[1] the Subsidiary Body for Scientific and Technological Advice (SBSTA) welcomed the coordinated response by the CEOS to the relevant needs of the GCOS implementation plan and those of the Convention, and the progress and commitment by space agencies involved in climate observations to address the space-based component of the GCOS and improve climate monitoring capabilities from space on a sustained basis. The SBSTA encouraged Parties that support the space agencies involved in global observations to continue, through CEOS, cooperation with and support to the GCOS, and to respond to the relevant needs identified in the 2010 updated GCOS implementation plan.[2] The SBSTA invited the CEOS to provide, by SBSTA 37, an updated report on progress made on major achievements in relevant areas.

3. In response of this invitation, India has submitted the above-mentioned progress report on behalf of the CEOS. An abridged version of this report is reproduced in this document. The full report will be made available at <www.ceos.org> and at <http://unfccc.int/3462>.

[1] FCCC/SBSTA/2010/13, paragraphs 52 and 53.
[2] The full title of the 2010 updated GCOS implementation plan reads "Update of the Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC".

4. In accordance with the procedure for miscellaneous documents, this submission is attached and reproduced* in the language in which it was received and without formal editing.

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Submission from India on behalf of the Committee on Earth Observation Satellites

The Response of the Committee on Earth Observation Satellites (CEOS) to the Global Climate Observing System Implementation Plan 2010 (GCOS IP-10)

Developed by CEOS and submitted to the United Nations Framework Convention on Climate Change (UNFCCC) Subsidiary Body on Scientific and Technological Advice (SBSTA)

24 September 2012

Abridged Version
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Executive Summary

At the sixteenth session of the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) in 2010, the 33rd session of the Subsidiary Body for Scientific and Technological Advice (SBSTA) invited the Committee on Earth Observation Satellites (CEOS) to provide, at SBSTA 37 at the COP in November 2012, an updated report on progress made on major achievements in relevant areas, such as in relation to responding to space-related needs of the updated Global Climate Observing System (GCOS) Implementation Plan of 2010[1]. This report represents the CEOS response to the requirements for space-based observations in GCOS IP-10 and its Satellite Supplement[2].

CEOS responded to the previous GCOS IP[3] in its 2006 report[4]. CEOS prepared and submitted an updated report[5] at SBSTA's 29th session in 2008. The SBSTA requested another update for its 33rd session in 2010, which CEOS prepared and submitted[6]. In addition to the implementation of 59 climate actions plans, a major initiative – CEOS Virtual Constellations – resulted in part from these activities. These virtual, space-based Constellations provide critical information on changes in land cover, precipitation, atmospheric composition, global sea level, ocean surface vector wind, ocean colour, and sea surface temperature. A CEOS Virtual Constellation is a set of space and ground segment capabilities operating together in a coordinated manner, in effect a virtual system, that overlaps in coverage in order to meet a combined and common set of Earth Observation requirements. The individual satellites and ground segments can belong to a single or to multiple owners.

Earth observation satellites provide a vital means of obtaining measurements of the climate system from a global perspective and comparing the behaviour of different parts of the globe for many of the Essential Climate Variables (ECVs) listed in GCOS IP-10. Their global nature distinguishes satellite observations from ground-based and airborne measurements that are more limited in spatial coverage, but nevertheless necessary to validate information derived from space and provide additional data, especially on variables not accessible from space.

Satellite climate data records that meet the GCOS requirements enable: climate monitoring, studies of trends and variability, climate research, assimilation into numerical weather prediction models to produce long-term reanalyses of the atmosphere and the Earth's surface, provision of boundary conditions for and verification of climate models, climate impacts, and, ultimately, decision-making in many societal sectors including agriculture, water resource and coastal management, forestry, transportation, and insurance applications.

[1] Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC [2010 Update] (GCOS IP-10).
[2] Systematic Observation Requirements for Satellite-Based Data Products for Climate 2011 Update: Supplemental details to the satellite-based component of GCOS-IP10.
[3] 2004 Global Climate Observing System (GCOS) Implementation Plan [IP]
[4] Satellite Observation of the Climate System: The Committee on Earth Observation Satellites [CEOS] Response to the 2004 Global Climate Observing System [GCOS] Implementation Plan [IP]
[5] Coordinated Response from Space Agencies Involved in Global Observations to the Needs Expressed in the Global Climate Observing System [GCOS] Implementation Plan: Update on Climate Actions
[6] 2010 Progress Report: Coordinated Response from Parties that Support Space Agencies Involved in Global Observations to the Needs Expressed in the Global Climate Observing System [GCOS] Implementation Plan of 2004

Reliable space-based observations can provide the authoritative records of climate change needed to empower governments and the private sector to make informed decisions on prevention, mitigation, and adaptation strategies.

GCOS IP-10 specifies the Actions required to implement a comprehensive observing system for the ECVs. The Plan includes some 138 specific Actions to be undertaken, mostly over the period 2011-2015, across the atmospheric, oceanic, and terrestrial domains. Of these, 47 involve space-based observations.

The Satellite Supplement to GCOS IP-10 provides additional technical detail related to satellite-based observations for each of the ECVs. It details the specific satellite data records that should be sustained in accordance with the GCOS Guidelines for Satellite-based Datasets and Products. In particular, for each ECV, the Satellite Supplement provides requirements for horizontal, vertical and temporal resolutions, accuracy, and stability. In addition, information is presented on benefits of meeting the requirements, rationale for the requirements, the requirements for satellite instruments and satellite datasets, calibration, validation and data archiving needs, adequacy/inadequacy of current datasets, immediate actions, partnerships and international coordination, links to the GCOS Implementation Plan, and other applications.

The current CEOS response is a significant step forward in defining a program to carry out the space-based contributions to the GCOS Implementation Plan. It represents a blueprint comprised of detailed plans for all of the ECVs accessible from space. For the actions specified for each ECV in GCOS IP-10 and its Satellite Supplement, CEOS has made an unprecedented effort to develop a roadmap with specificity, actionability, responsibility, and desired outcomes in terms of quantitative metrics. The plans for each action include the lead and cooperating CEOS Member Agencies responsible for carrying out the action, descriptions of the specific deliverables, and activities planned for implementation over the next five years. It was prepared by the scientific and technical experts who, with the teams they have assembled, will be responsible for leading the implementation of the action plans.

Going beyond its response to the previous GCOS IP (GCOS IP-04), CEOS has made a concerted attempt to address the quantitative target metrics established by GCOS IP-10 for each ECV's accuracy, stability, and spatial resolutions; this CEOS response includes these target metrics and the metrics that CEOS plans to achieve for each ECV. The specification of metrics places the entire enterprise on a much firmer foundation.

Achieving the metrics laid out in this response represents a significant challenge to the CEOS community and will require a degree of coordination and collaboration never achieved before. CEOS, at its 24th Plenary meeting in 2010, responded to this challenge by establishing a new Working Group on Climate (WGClimate), to coordinate and encourage collaborative activities among the world's space agencies in the area of climate monitoring. The continued development and implementation of the CEOS Virtual Constellations are vital to success. Close collaboration among CEOS, the GCOS program, World Climate Research Programme (WCRP) satellite observational and data programs, and national climate programs is also vital.

Compiling the detailed action plans since the December 2011 release of the update to the Satellite Supplement represented a significant undertaking. In some cases, action plans are still incomplete. The process and metrics defined provide a useful mechanism for updating and monitoring the actions. Even if the current action plans are not exhaustively completed, they can be updated over time as more information becomes available. This report should be considered a living, working document.

1 Introduction

1.1 Purpose of the Report

1.2 Background

The Global Climate Observing System (GCOS), a joint undertaking of the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific, and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU), was established in 1992 to ensure that the observations and information needed to address climate-related issues are obtained and made available to all potential users.

At the 7th Conference of the Parties (COP 7) to the United Nations Framework Convention on Climate Change (UNFCCC) in 2001, the UNFCCC Subsidiary Body on Scientific and Technological Advice (SBSTA) invited GCOS to consider an integrated (satellite and *in situ*) approach, including the exploitation of new and emerging methods of observation to the measurement of climate change. At COP 9 in 2003, GCOS was invited to develop a phased 5-10 year implementation plan. COP 10 in 2004 invited Parties with space agencies to have those space agencies provide a coordinated response to the recommendations in the 2004 implementation plan. At COP 11 in 2005, the United States, Japan, and other Parties supported the offer of the Committee on Earth Observation Satellites (CEOS) to provide a coordinated response to the recommendations in the GCOS Implementation Plan. At COP 12 in 2006, the SBSTA:

- Welcomed the CEOS report[7] requested by COP 10 and describing the coordinated response by space agencies involved in Earth observations to the needs expressed in the GCOS Implementation Plan;
- Invited Parties that support space agencies to enable those agencies to implement the actions identified and to continue responding in a coordinated manner through CEOS;
- Encouraged the continued partnership between GCOS and CEOS.

COP 13 in 2007 commended CEOS on the progress made in 2007 in implementing actions for space agencies identified in the 2004 GCOS Implementation Plan and invited CEOS to provide an updated progress report at SBSTA 29 in 2008. CEOS prepared and submitted its report[8] at SBSTA's 29th session in 2008. The SBSTA requested another update for its 33rd session in 2010, which CEOS prepared and submitted[9].

COP 15 expressed its appreciation to CEOS for its coordinated response, on behalf of Parties that support space agencies involved in global observations, to the needs expressed in the GCOS implementation plan and invited GCOS to update its implementation plan, taking into account emerging needs in climate observation, in particular those relating to adaptation activities. In line with the conclusions of SBSTA 33, CEOS has been invited to provide, by SBSTA 37 at the COP 18 in November 2012, an updated report on progress made on major achievements in relevant areas (such as in relation to responding to space-related needs of the GCOS IP). This document provides CEOS's response.

[7] Satellite Observation of the Climate System: The Committee on Earth Observation Satellites [CEOS] Response to the 2004 Global Climate Observing System [GCOS] Implementation Plan [IP],

[8] Coordinated Response from Space Agencies Involved in Global Observations to the Needs Expressed in the Global Climate Observing System [GCOS] Implementation Plan: Update on Climate Actions

[9] 2010 Progress Report: Coordinated Response from Parties that Support Space Agencies Involved in Global Observations to the Needs Expressed in the Global Climate Observing System [GCOS] Implementation Plan of 2004

1.3 The Essential Role of Satellites in a Climate Observing System

Earth observation satellites provide a vital means of obtaining observations of the climate system from a global perspective and comparing the behaviour of different parts of the globe for many of the Essential Climate Variables. Their global nature distinguishes satellite observations from ground-based and airborne measurements that are more limited in spatial coverage, but nevertheless necessary to constrain and validate information derived from space, and provide data on variables not accessible from space.

Satellite climate data records that meet the GCOS requirements enable climate monitoring, studies of trends and variability, climate research, assimilation into numerical weather prediction models to produce long-term reanalyses of the atmosphere and surface, provision of boundary conditions for and verification of climate models, climate impacts, and, ultimately, decision-making in many societal sectors including agriculture, water resource and coastal management, forestry, transportation, and insurance applications.

> Reliable space-based observations can provide the authoritative, irrefutable records of climate change needed to empower governments and the private sector to make informed decisions on prevention, mitigation, and adaptation strategies.

The conventional (non-satellite) observational systems contributing to the GCOS include atmospheric, oceanic, and terrestrial components. The atmospheric component includes the GCOS Surface Network (GSN), which provides a global baseline of the surface climate in which we live; the global baseline GCOS upper air network (GUAN), and the GCOS Reference Upper-Air Network (GRUAN), which measures temperature, humidity, and winds aloft; the World Meteorological Organization (WMO) Global Atmosphere Watch (GAW) global baseline ozone networks and the WMO GAW Global Atmospheric CO_2 and CH_4 Monitoring Networks.

The surface ocean network provides information about the patterns of ocean surface temperature, pressure, winds, salinity, sea level, waves and sea ice that are important both to the global climate and its regional distribution. Its main systems are: (a) the global baseline network of tide gauges; (b) an enhanced drifting buoy array; (c) an enhanced Tropical Moored Buoy network; (d) an enhanced Voluntary Observing Ships Climatology (VOSClim) network; and (e) a globally-distributed reference mooring network. The sub-surface ocean network provides critical information on ocean climate variability and change and includes: (a) the Argo profiling float array; (b) the systematic sampling of the global ocean full-depth water column; (c) the Ship-of-Opportunity Expendable Bathythermograph (XBT) trans-oceanic sections; and (d) the Tropical Moored Buoy and reference mooring networks.

The conventional climate observing system in the Terrestrial Domain remains the least well-developed component of the global system. The Global Terrestrial Observing System (GTOS), a program for observations, modeling, and analysis of terrestrial ecosystems to support sustainable development, is leading the effort to expand land observations for climate applications. Current networks monitor River Discharge (GTN-R), Glaciers (GTN-G), Hydrology (GTN-H), Lake Level/Area (GTN-L), and Permafrost (GTN-P). In addition, Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) provides ongoing space-based and *in situ* observations of forests and other vegetation cover, and Coastal-GTOS (C-GTOS) focuses on global and regional change in coastal areas.

While the conventional observing networks provide critical climate measurements at a number of points around the globe, and observe some ECVs currently unobservable from space at required accuracies, (*e.g.,*

surface air temperature), they have limitations when it comes to observing global climate change. For the most part, the atmospheric observations are limited to the land areas of the Earth and are highly concentrated in the major population centers of the developed countries. Ocean areas – 70% of the globe – are largely under-sampled in terms of the atmospheric measurements. And there are also large gaps in the coverage of surface and sub-surface ocean measurements. *In situ* terrestrial observation networks also have large gaps. Constructing a reliable picture of global climate change from an observing system that has such large voids is an impossible task.

Satellites, and complimentary *in situ* networks, provide the global coverage needed to observe and document world-wide climate change. A single radiometer on a polar orbiting satellite observes the entire Earth on a daily basis. Instruments on geostationary satellites monitor the diurnal cycle of the disk of Earth below them. Together the polar and geostationary environmental satellites maintain a constant watch on the entire globe. However, as noted above, in many cases *in situ* measurements are needed to validate satellite observations.

In the satellite-based Earth observations community, Research to Operations (R2O) has been historically used to describe the transfer of organizational responsibility (and usually funding responsibility) for a particular sensor from a research agency to an operational agency. The climate community is finding the concept, or at least implementation of the concept, to be lacking. Climate record processing requires dedicated expert understanding of new and legacy climate sensors, as well as sustained support activities of both research and operational agencies. Research Agencies have invested in the creation of consistent time series satellite data sets over decades. They also have made significant investments in calibration laboratories, airborne sensors, processing facilities, and ground networks that support calibration and validation activities for satellite programs. These contributions to climate science will be a vital element of a collaborative climate observation and processing architecture as operational climate services emerge in national agencies.

2 The Global Climate Observing System Implementation Plan 2010 (GCOS-138)

2.1 Introduction

This section summarizes the background and purpose of the 2010 Update of the GCOS IP and presents an overview of its recommendations. The plan proposes implementation Actions that are both currently technically and economically feasible for systematic observation on global scales and have a high impact on UNFCCC and the Intergovernmental Panel on Climate Change (IPCC) requirements for climate change detection, attribution, prediction, impact assessment, and adaptation.

2.2 Background

The GCOS Steering Committee and Secretariat, in consultation with the GCOS sponsors WMO, IOC/UNESCO, UNEP and ICSU, the sponsors of other contributing observing systems, and a wide cross-section of climate and observing system experts prepared the GCOS IP-10[10], to respond to a request by Parties to the UNFCCC at the 30th session of the UNFCCC Subsidiary Body on Scientific and Technological Advice (SBSTA) in June 2009 (cf. Appendix 1 of the full Plan), and in accord with the general guidance provided by the UNFCCC Conference of the Parties (COP) 9 in its request for the IP-04 (Decision 11/CP.9).

This 2010 edition of the *Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC* (GCOS IP-10) replaces a similarly titled Plan (GCOS IP-04) which was published in 2004. Its purpose is to provide an updated set of Actions required to implement and maintain a comprehensive global observing system for climate that will address the commitments of the Parties under Articles 4 and 5 of the UNFCCC and support their needs for climate observations in fulfillment of the objectives of the Convention. This revised Plan updates the Actions in the IP-04, taking account of recent progress in science and technology, the increased focus on adaptation, enhanced efforts to optimize mitigation measures, and the need for improved prediction and projection of climate change. It focuses on the timeframe 2010-2015.

2.3 Purpose

The GCOS Implementation Plan 2010, if fully implemented by the Parties, both individually and collectively, will provide those global observations of the Essential Climate Variables and their associated products to assist the Parties in meeting their responsibilities under Articles 4 and 5 of the UNFCCC. In addition, although the Plan does *not* include changing needs for limited duration observations in research studies, it will provide most of the essential observations required by the World Climate Research Programme (WCRP) and IPCC. Specifically the proposed system would provide information to:

- Characterize the state of the global climate system and its variability;
- Monitor the forcing of the climate system, including both natural and anthropogenic contributions;
- Support the attribution of the causes of climate change;
- Support the prediction of global climate change;
- Enable projection of global climate change information down to regional and local scales; and

[10] Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (2010 Update) (GCOS-138)

- Ensure the availability of information important in impact assessment and adaptation, and for the assessment of risk and vulnerability, including the characterization of extreme events.

2.4 Strategic Approach

As part of its strategic approach, GCOS IP-10 lists the following criteria for including items for implementation:

- Clearly significant and citable benefits toward meeting the needs stemming from Articles 4 and 5 of the UNFCCC for specific climate observations in support of impact assessment, prediction and attribution of climate change, and the amelioration of, and adaptation to, projected future changes;
- Feasibility of an observation, as determined by the current availability of an observation or by knowledge of how to make an observation with acceptable accuracy, stability, and resolution in both space and time;
- Ability to specify a tractable set of implementing Actions (where "tractable" implies that the nature of the Action can be clearly articulated, that the technology and systems exist to take the Action, and that an Agent for Implementation well-positioned to either take the Action or to ensure that it is taken can be specified); and
- Cost effectiveness – the proposed Action is economically justified.

2.5 Overview of Recommendations

GCOS IP-10 expresses its recommendations in terms of a list of general needs followed by specifications of detailed climate actions to meet the requirements of a trustworthy Global Climate Observing System. GCOS IP-10 covers in-situ as well as satellite observations; a Satellite Supplement to GCOS IP-10, expanding on the requirements for satellite observations and data products, is summarized in the next section of this Response. The climate Actions are organized around the Essential Climate Variables (ECVs) in each of the climate system domains (Atmospheric, Oceanic, and Terrestrial) (see Table 1). It is these variables for which international exchange is required for both current and historical observations. In addition, GCOS IP-10 includes a list of overarching/cross-cutting actions that pertain to all of the ECVs. For each ECV, one or more climate actions are specified for implementation.

Table 1: Essential Climate Variables that are both currently feasible for global implementation and have a high impact on UNFCCC requirements

Domain	Essential Climate Variables
Atmospheric (over land, sea and ice)	**Surface:** Air temperature, Wind speed and direction, Water vapour, Pressure, Precipitation, Surface radiation budget. **Upper-air:** Temperature, Wind speed and direction, Water vapour, Cloud properties, Earth radiation budget (including solar irradiance). **Composition:** Carbon dioxide, Methane, and other long-lived greenhouse gases, Ozone and Aerosol, supported by their precursors
Oceanic	**Surface:** Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Surface current, Ocean colour, Carbon dioxide partial pressure, Ocean acidity, Phytoplankton. **Sub-surface:** Temperature, Salinity, Current, Nutrients, Carbon dioxide partial pressure, Ocean acidity, Oxygen, Tracers.
Terrestrial	River discharge, Water use, Groundwater, Lakes, Snow cover, Glaciers and ice caps, Ice sheets, Permafrost, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (FAPAR), Leaf area index (LAI), Above-ground biomass, Soil carbon, Fire disturbance, Soil moisture.

For each ECV, GCOS IP-10 presents: the required climate **Action**, **Who** would be responsible for implementing the Action, the **Time Frame** for carrying out the Action, a **Performance Indicator** to measure performance on the Action, and estimated **Annual Cost Implications** for implementing the Action. For example, for the ECV precipitation, one of the actions listed is:

ECV – Precipitation

Action A8

Action: Ensure continuity of satellite precipitation products.
Who: Space agencies.
Time-Frame: Continuous.
Performance Indicator: Long-term homogeneous satellite-based global precipitation products.
Annual Cost Implications: 10-30M US$ (for generation of climate products, assuming missions funded for other operational purposes) (Mainly by Annex-I Parties).

In addition, the importance of the ECVs to climate knowledge is explained and the status of current observing systems for implementing the actions is discussed.

GCOS IP-10 lists a total of 138 climate implementation actions for *in situ* observations, satellite observations, and cross-cutting applications. The next section of this response summarizes the Satellite supplement to GCOS IP-10, which expands on the requirements for implementing the satellite related actions.

3 Satellite Supplement to the GCOS Implementation Plan

3.1 Introduction

The GCOS Steering Committee has also prepared a special Satellite Supplement[11]. This section summarizes the purpose of the Satellite Supplement and presents an overview of its requirements for satellite observations and data products.

3.2 Purpose

GCOS IP-10 recognizes the importance of deriving products and data records of physical variables from the measurements made by satellites. The Satellite Supplement adds details to the GCOS IP-10 related to the generation of these products and the associated datasets. It is intended mainly to assist Parties that support Earth observation from space to respond to the requirements of the GCOS IP-10. It also has relevance to all Parties that access satellite data records and/or use derived products for climate applications. Furthermore, a wide range of Parties can contribute the *in situ* data needed for the calibration of satellite instruments, for the validation of satellite data and derived products, and for incorporation of satellite data into integrated products, such as those provided by reanalysis.

The Satellite Supplement provides additional technical detail to GCOS IP-10 related to satellite-based observations for each of the Essential Climate Variables (ECVs) in each of the climate system domains (Atmospheric, Oceanic, and Terrestrial) listed in Table 1. In particular, it details the specific satellite data records that should be sustained in accordance with the GCOS Guideline for Satellite-based Datasets and Products (Appendix 1), as well as other important supplemental satellite observations that are needed on occasion or at regular intervals.

Table 2: ECVs for which satellite observations make a significant contribution

Domain	Essential Climate Variables
Atmospheric (over land, sea and ice)	Surface wind speed and direction; precipitation; upper-air temperature; upper-air wind speed and direction; water vapour; cloud properties; Earth radiation budget (including solar irradiance); carbon dioxide; methane and other long-lived greenhouse gases; and ozone and aerosol properties, supported by their precursors.
Oceanic	Sea-surface temperature; sea-surface salinity; sea level; sea state; sea ice; ocean colour.
Terrestrial	Lakes; snow cover; glaciers and ice caps;, ice sheets; albedo; land cover (including vegetation type); fraction of Absorbed Photosynthetically Active Radiation (FAPAR); Leaf Area Index (LAI); above-ground biomass; fire disturbance; soil moisture.

3.3 Overview of Requirements

The Satellite Supplement lists the following general high priority critical issues to be addressed by both the space agencies and the other implementation agents:

[11] Systematic Observation Requirements for Satellite-Based Data Products for Climate 2011 Update: Supplemental details to the satellite-based component of the "Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC [2010 Update]."

- Continuity and improvement of key satellite and *in situ* networks;
- Generation of high-quality global datasets for the ECVs;
- Improvement of access to basic satellite datasets and high-quality global products;
- Enhancement of the participation of least-developed countries and small island developing states; and
- Strengthening of national and international infrastructures.

The specifications given in the Satellite Supplement directly address these priorities

Tables 3 through 5 provide an overview of the requirements for products and sustained satellite data records that are detailed in the Satellite Supplement. For each ECV, two types of information products are required: 1) Fundamental Climate Data Records (FCDRs), which represent the basic satellite observations (e.g., radiances, backscatter); and 2) Global Products requiring Satellite Observations, or Thematic Climate Data Records (TCDRs), which are the climate variables derived from the FCDRs. The last column in each table assigns a product number to each ECV along with its links to GCOS IP-10 Actions (in parentheses). In addition to individual ECV requirements, the Satellite Supplement also includes cross-cutting requirements that apply to all of the ECVs.

Table 3: Overview of Products – Atmosphere

ECV	Global Products requiring Satellite Observations	Fundamental Climate Data Records required for Product Generation (from past, current, and future missions)	Product Numbers (IP-10 Reference Actions)
Surface Wind Speed and Direction	Surface wind retrievals	Passive microwave radiances and radar backscatter	A.1 (A11)
Precipitation	Estimates of liquid and solid precipitation, derived from specific instruments and provided by composite products	Passive microwave radiances Geostationary VIS/NIR/IR radiances	A.2 (A6, A8, A9, A10)
Upper-air Temperature	Upper-air temperature retrievals Temperature of deep atmospheric layers	Passive microwave and IR radiances GNSS radio occultation bending angles	A.3.1 A.3.2 (A20, A21)
Upper-air Wind Speed and Direction	Upper-air wind retrievals	VIS/IR imager radiances Doppler wind lidar	A.4 (A11)
Water Vapour	Total column water vapour Tropospheric and lower-stratospheric profiles of water vapour Upper tropospheric humidity	Passive microwave radiances; UV/VIS imager radiances; IR and microwave radiances; Limb soundings	A.5.1 A.5.2 A.5.3 (A7, A21, A22, A26)
Cloud Properties	Cloud amount, top pressure and temperature, optical depth, water path and effective particle radius	VIS/IR imager radiances IR and microwave radiances, lidar	A.6.1 A.6.2 A.6.3 A.6.4 A.6.5 A.6.6 (A23, A24)
Earth Radiation Budget	Earth radiation budget (top-of-atmosphere and surface) Total and spectrally-resolved solar irradiance	Broadband radiances Spectrally-resolved solar irradiances Geostationary multispectral imager radiances	A.7.1 A.7.2 (A14, A25)
Carbon Dioxide, Methane and other GHGs	Retrievals of greenhouse gases, such as CO_2 and CH_4, of sufficient quality to estimate regional sources and sinks	NIR/IR radiances	A.8.1 (A26, A28, A29)
Ozone	Total column ozone Tropospheric ozone Ozone profiles from upper troposphere to mesosphere	UV/VIS and IR/microwave radiances, from nadir and limb sounding	A.9.1 A.9.2 A.9.3 (A26, A32)

Aerosol Properties	Aerosol optical depth Aerosol single scattering albedo Aerosol layer height Aerosol extinction profiles from the troposphere to at least 35km	UV/VIS/NIR/SWIR and TIR radiances UV/VIS/IR limb sounding (scatter, emission, occultation) Lidar profiling	A.10.1 A.10.2 A.10.3 A.10.4 (A33)
Precursors supporting the Ozone and Aerosol ECVs	Retrievals of precursors for aerosols and ozone such as NO_2, SO_2, HCHO and CO	UV/VIS/NIR/SWIR and TIR radiances UV/VIS/IR limb sounding (scatter, emission, occultation) Lidar profiling	A.11.1 (A26, A27, A34)

Table 4: Overview of Products – Oceans

ECV	Global Products requiring Satellite Observations	Fundamental Climate Data Records required for Product Generation (from past, current and future missions)	Product Numbers (IP-10 Reference Actions)
Sea-surface Temperature	Integrated sea-surface temperature analyses based on satellite and *in situ* data records	Single and multi-view IR and microwave imager radiances	O.1 (O4, O7, O8)
Sea-surface Salinity	Datasets for research on identification of changes in sea-surface salinity	Microwave radiances	O.2 (O12)
Sea Level	Sea level global mean and regional variability	Altimetry	O.3 (O10)
Sea State	Wave height, supported by other measures of sea state (wave direction, wavelength, time period)	Altimetry	O.4 (O16)
Sea Ice	Sea-ice concentration/extent/edge, supported by sea-ice thickness and sea-ice drift	Passive and active microwave and visible imager radiances, supported by Synthetic Aperture Radar (SAR) altimetry	O.5 (O18, O19, O20)
Ocean Colour	Ocean colour radiometry – water leaving radiance Oceanic chlorophyll-a concentration, derived from ocean colour radiometry	Multispectral VIS imager radiances	O.6.1, O.6.2 (O15, O23)

Table 5: Overview of Products – Terrestrial

ECV or supporting variable[5]	Global Products requiring Satellite Observations	Fundamental Climate Data Records required for Product Generation (from past, current and future missions)	Product Numbers (IP-10 Reference Actions)
Lakes	Lake levels and areas of lakes in the Global Terrestrial Network for Lakes (GTN-L)	VIS/NIR imager radiances, and radar imager radiances Altimetry	T.1.1 T.1.2 (T8)
Snow Cover	Snow areal extent, supplemented by snow water equivalent	Moderate-resolution VIS/NIR/IR and passive microwave imager radiances	T.2 (T16)
Glaciers and Ice Caps	2D vector outlines of glaciers and ice caps (delineating glacier area), supplemented by digital elevation models for drainage divides and topographic parameters	High-resolution VIS/NIR/SWIR optical imager radiances, supplemented by microwave InSAR and along-track optical stereo imaging	T.3.1 T.3.2 (T17)
Ice Sheets	Ice-sheet elevation changes, supplemented by fields of ice velocity and ice-mass change	Radar and laser altimetry, supplemented by SAR, gravity	T.4 (T20)
Albedo	Reflectance anisotropy (BRDF), black-sky and white-sky albedo	Multispectral and multiangular imager radiances	T.5 (T3, T24, T25)
Land Cover	Moderate-resolution maps of land-cover type High-resolution maps of land-cover type, for the detection of land-cover change	Moderate-resolution multispectral VIS/NIR imager radiances High-resolution multispectral VIS/NIR imager radiances, supplemented by radar	T.6.1 T.6.2 (T26, T27, T28)
FAPAR	Maps of the Fraction of Absorbed Photosynthetically Active Radiation	VIS/NIR multispectral imager radiances	T.7 (T3, T31, T29)
LAI	Maps of Leaf Area Index	VIS/NIR multispectral imager radiances	T.8 (T3, T29, T30,T31)
Biomass	Regional and global above-ground forest biomass	Long-wavelength radar and lidar	T.9 (T32)
Fire Disturbance	Maps of burnt area, supplemented by active-fire maps and fire-radiative power	VIS/NIR/SWIR/TIR moderate-resolution multispectral imager radiances	T.10 (T35, T36, T37, T38, T39)
Soil Moisture	Research towards global near-surface soil-moisture map (up to 10cm soil depth)	Active and passive microwave	T.11 (T13, T14)
Land-surface Temperature	Land-surface temperature records to support generation of land ECVs	High-resolution IR radiances from geostationary and polar-orbiting satellites; Microwave radiances from polar-orbiting satellites	T.12 (T5, T13,

For each ECV, the Satellite Supplement explains the importance of the ECV for climate knowledge and available observing systems, and then provides requirements for horizontal, vertical, and temporal resolutions, accuracy, and stability. In addition, information is presented on the following: benefits of meeting the requirements, rationale for the requirements, the requirements for satellite instruments and satellite datasets, calibration, validation and data archiving needs, adequacy/inadequacy of current datasets, immediate actions, partnerships and international coordination, links to the GCOS Implementation Plan, and other applications.

4 Approach to Preparation of the CEOS Response to GCOS IP-10

4.1 Introduction

This section reviews the CEOS response to the previous GCOS implementation plan (GCOS IP-04), points out the key differences in approach between the present response and the previous one, and then describes the process that was used to create this response to GCOS IP-10.

4.2 Review of the CEOS Response to GCOS IP-04

In 2006, CEOS prepared a response[12] to the GCOS IP-04 requirements for satellite observations and data. CEOS evaluated the adequacy of the current observations system to meet these requirements, and developed an action plan to address inadequacies. The CEOS report identified 59 actions that covered key aspects of climate-related observations of the atmosphere, ocean and land. The report emphasized the importance of satellite measurements of the highest reliability to provide the long-term records needed to monitor climate change. In 2007, CEOS Members initiated work in close coordination with GCOS and the Group on Earth Observations (GEO), and with other relevant fora, such as the Coordination Group for Meteorological Satellites (CGMS) and the WMO, to implement the climate actions. To this end, CEOS assembled international teams, representing all concerned CEOS Agencies to implement the Climate Action Plan.

The SBSTA invited CEOS to report on progress made in its efforts at its 33rd session in November-December 2010. CEOS prepared and submitted its progress report[13] in October 2010. It contained inputs from CEOS climate action teams and other stakeholders on the current status of the 59 CEOS Climate Actions. The report reviewed key accomplishments and described future plans. In addition, progress on forest carbon, terrestrial validation, and early warning for disasters related to climate change was provided. The report also summarized additional satellite-based climate observation and data record activities by individual space agencies and other international coordination bodies such as the WCRP, WMO, and CGMS.

One of the key activities in the CEOS Climate Action Plan in support of GCOS IP-04 and the space component of the Global Earth Observation System of Systems (GEOSS) is the development of virtual, space-based Constellations to provide critical information on changes in land cover, precipitation, atmospheric composition, global sea level, ocean surface vector wind, ocean colour, and sea surface temperature. A CEOS Virtual Constellation is a set of space and ground segment capabilities operating together in a coordinated manner, in effect a virtual system that overlaps in coverage in order to meet a combined and common set of Earth Observation requirements. The individual satellites and ground segments can belong to a single or to multiple owners. The Constellation concept builds upon or serves to refocus already existing projects and activities. In particular, it offers opportunities to share experience in the development of algorithms, standardize data products and formats, exchange information regarding the calibration and validation of measurements, facilitate timely exchange of and access to data products from

[12] Satellite Observation of the Climate System-the Committee on Earth Observation Satellites (CEOS) Response to the Global Climate Observing System (GCOS) Implementation Plan

[13] 2010 Progress Report: Coordinated Response from Parties that Support Space Agencies Involved in Global Observations to the Needs Expressed in the Global Climate Observing System (GCOS) Implementation Plan of 2004

existing and planned missions, and facilitate planning of new missions – ranging from coordinating orbits to optimizing observational coverage to sharing implementation of mission components.

4.3 The CEOS Response: GCOS IP-10 vs. GCOS IP-04

While the current response is similar to that for GCOS IP-04 in that it also uses input from the GCOS Satellite Supplement and reinforces the needs called out by the supplement, it is also more specific in a number of ways. This CEOS response gives more ***actionable*** climate actions and assigns a high level of effort to each action. It identifies the specific responsible lead CEOS Agency (rather than stating CEOS Agencies in general) as well as the names of team leads and members for each action. And, in particular, it details the quality metrics for each ECV. These metrics for the satellite-based data sets include requirements for accuracy, stability, and spatial and temporal resolutions. They include both the target requirements established by the GCOS and the metrics expected to be achieved in each action plan. The plans also include timetables, and for some climate actions, additional activities not called out by GCOS but that may be considered important by CEOS.

4.4 The Process

The central idea was to develop a CEOS action execution plan for each of the 47 satellite-related Actions identified in GCOS IP-10. To start the process, the CEOS Climate Societal Benefit Area (SBA) Coordinator, in consultation with senior community professionals, identified leads for the atmosphere, ocean and land domains. The domain leads were tasked to designate Subject Matter Experts (SMEs) for each CEOS action and to select the community feedback group(s) that would vet the CEOS climate action plans. The domain leads were also responsible for ensuring that each action was actionable with a high level of effort identified.

In developing their plans, the domain leads and SMEs consulted with the expert community for each action, the authors of the CEOS response to the 2004 GCOS IP, the four CEOS Working Groups (Calibration and Validation [WGCV], Information Systems and Services [WGISS], Climate [WGClimate], Capacity Building and Data Democracy [WGCapD]), and seven CEOS Virtual Constellations (Atmospheric Composition [ACC-VC], Land Surface Imaging [LSI-VC], Ocean Colour Radiometry [OCR-VC], Ocean Surface Topography [OST-VC], Ocean Surface Vector Wind [OSVW-VC], Precipitation [PC-VC], and Sea Surface Temperature [SST-VC]). The CEOS Climate SBA Coordinator and the domain leads coordinated with other stakeholders: WMO, Sustained Co-Ordinated Processing of Environmental Satellite Data for Climate Monitoring (SCOPE-CM), Global Space-based Inter-Calibration System (GSICS), WCRP, and CGMS to address the GCOS actions that do not have a clear association with an existing CEOS Constellation or Working Group.

This CEOS response builds on CEOS activities initiated in response to the GCOS IP-04, and takes advantage of international working groups, coordination bodies, and ongoing relevant international efforts, such as those of the WCRP and Global Observation for Forest and Land Cover Dynamics (GOFC-GOLD), for example, to review and vet the action execution plans.

The basic building block is a generic template for each GCOS/CEOS action. The domain leads and SMEs compiled the inputs for these templates. Since they contain the same type of information, they are readily comparable and their execution will be easy to track. After a number of iterations, the template below was adopted for developing the CEOS response to the requirements for the satellite-related actions of GCOS IP-10.

Template: The CEOS Response to the GCOS Implementation Plan & Satellite Supplement (Describing 2011-2015 CEOS Activities)

Throughout the completion of this template, please bear in mind the GCOS IP-10 (2010 update)/SS content associated with this action in its entirety. These templates will compile to form a comprehensive, coordinated CEOS response to addressing the satellite Earth observation needs discussed thoroughly in the GCOS Implementation Plan and Satellite Supplement (IP/SS).

Action:

Who:

Time-Frame:

Performance Indicator:

Annual Cost Implications:

Input for each action taken directly from GCOS IP-10

CEOS Entities:

- CEOS Agency Leads:
- CEOS Agency Contributors:
- CEOS Coordination Mechanisms:

Team:

- Leads:
- Members:

International Coordination Bodies:

Relevant existing CEOS actions:

CEOS Deliverable(s) as related to this GCOS Action –

All current and planned CEOS activities, outcomes, and deliverables that address the needs identified in the GCOS IP-10/SS for this action. Describe each one, including a brief recap of the significance of the deliverables' role in climate observations (it is not necessary to restate the content of the GCOS IP-10/SS). Elaborate or add any relevant content as necessary. Please also discuss the needs that CEOS is not currently planning to address, but that CEOS agrees are important. Include satellites/instruments, products/programs, coordination, etc., making sure to fully address the content of GCOS IP-10/SS sections such as "Requirements for satellite instruments and satellite datasets" and "Immediate action, partnerships, and international coordination", etc.

- Specific Deliverable #1:
- Specific Deliverable #2
- Specific Deliverable #3

Accuracy –

Target and planned accuracy capabilities, if applicable, specific to each of the deliverables mentioned above. Target accuracies are taken for the GCOS IP-10 Satellite Supplement. Planned accuracies are those planned or implementation in the Action plan.

- For deliverable 1
- For deliverable 2
- For deliverable 3

Stability –

Target and planned stability capabilities, if applicable, specific to each of the deliverables mentioned above. Target stabilities are taken for the GCOS IP-10 Satellite Supplement. Planned stabilities are those planned or implementation in the Action plan.

- For deliverable 1
- For deliverable 2
- For deliverable 3

Horizontal resolution –

Target and planned horizontal resolution capabilities, if applicable, specific to each of the deliverables mentioned above. Target horizontal resolutions are taken for the GCOS IP-10 Satellite Supplement. Planned horizontal resolutions are those planned or implementation in the Action plan.

- For deliverable 1
- For deliverable 2
- For deliverable 3

Vertical resolution –

Target and planned vertical resolution capabilities, if applicable, specific to each of the deliverables mentioned above. Target vertical resolutions are taken for the GCOS IP-10 Satellite Supplement. Planned vertical resolutions are those planned or implementation in the Action plan.

- For deliverable 1
- For deliverable 2
- For deliverable 3

Data & Science Requirements –

Discuss and respond to the data/science requirements mentioned in the GCOS IP-10/SS as related to this GCOS action and the relevant CEOS deliverables. What does CEOS need in terms of data and science help, in order to accomplish these deliverables? Why are they needed and who can help?

- For deliverable 1
- For deliverable 2
- For deliverable 3

Planned activities/time frames to meet deliverables (2011 – 2015) –

Include resources/websites where a reader might find more information on these activities, if possible.

- For deliverable 1
- For deliverable 2
- For deliverable 3

Are the above activities sufficient to accomplish the GCOS action? If not, what is missing? What additional activities in support of this GCOS action can be accomplished with additional funding? Discuss.

- For deliverable 1
- For deliverable 2
- For deliverable 3

Supporting Material from GCOS IP-10:

The inputs received from the leading experts for each of the actions were compiled into a single response and iterated with the contributors to ensure accuracy and clarity. The consolidated draft response was reviewed by CEOS to ensure that it was consistent across the Atmosphere, Ocean, and Terrestrial domains. The draft report was then reviewed by the CEOS Working Group on Climate (WGClimate), and approved for presentation to the SBSTA in November 2012.

5 Planned CEOS Actions in Response to GCOS IP-10

5.1 Introduction

This section summarizes the Actions to be undertaken by CEOS Agencies and their partners in response to the 2010 GCOS Implementation Plan and its Satellite Supplement. All the Actions are tied to the ECVs and, for easy traceability, each CEOS Action bears the same number as its corresponding GCOS IP action. In addition, each Action includes the relevant 2011Satellite Supplement climate product numbers (referred to as **SS: numbers**). The Actions listed here incorporate the key elements of the Action Templates submitted by the Domain Leads and Subject Matter Experts. These elements are: lead and contributing agencies; international coordination bodies; specific deliverables; quantitative metrics for accuracy, stability, horizontal resolution, and vertical resolution; and planned activities/time frames to meet deliverables (2011-2015). For each ECV, a short explanation of its importance is also presented.

The Satellite Supplement prescribes quantitative metrics for accuracy, stability, and resolution, Accuracy is the closeness of measured values to true values. Accuracy may be thought of as the systematic error of a climate variable with respect to a standard reference, such as the International Standard (SI). Stability is the change of accuracy with time. Stability may be thought of as the extent to which the accuracy remains constant with time. Stability is measured by the maximum excursion of the short- term average measured value of a variable under identical conditions over some time period, for example, a decade. The smaller the maximum excursion, the greater the stability of the data set.

The Action Plans include both target and planned values for the metrics. The target values are taken from Satellite Supplement to GCOS IP-10, which defines the term “target” as the resolutions, uncertainties and error variations below which there would be no significant additional value for current climate applications from further reductions. The planned values are those expected to be achieved through implementation of the action. Target and planned values are missing from some Climate Actions because they were not included in the Satellite Supplement or were not yet available from the Climate Action Teams.

The Action Templates are designed for space-based observing systems. For some actions – for example, actions centering on coordination activities or assistance in establishing ground-based networks or data services – the Action Templates are not applicable and are replaced by a textual description of the CEOS response.

For a complete listing of the 47 Action Templates, please refer to the full report *Response of the Committee on Earth Observation Satellites (CEOS) to the Global Climate Observing System Implementation Plan (GCOS IP-10)*, available at www.ceos.org.

Conclusion

In 2006, CEOS responded to the first Implementation Plan for the Global Climate Observing System (GCOS IP-04) by preparing a climate action plan that led to coordinated programs and the development of Virtual Constellations of satellites to meet the requirements for space observations set forth in the Plan. The present document continues the close cooperation between CEOS and GCOS by responding to the updated requirements for space observations detailed in the GCOS IP-10 and its Satellite Supplement.

The current response represents a significant step forward in defining a program to carry out the space-based contributions to the GCOS IP-10. It represents a blueprint comprised of detailed plans for all of the ECVs which can be assessed by space-based instruments. For the actions specified for each ECV in GCOS IP-10 and its Satellite Supplement, an unprecedented effort was made to develop a roadmap that included the lead and cooperating agencies responsible for carrying out the Action, specific deliverables, and activities planned for implementation over the next five years. It was prepared by the scientific and technical experts who, with the teams they have assembled, will be responsible for leading the implementation of the Action Plans.

Going beyond GCOS IP-04, the GCOS IP-10 and its Satellite Supplement have made a special effort to establish target quantitative metrics for each ECV's accuracy, stability, and spatial resolutions. This CEOS response includes these target metrics and the metrics that are planned to be achieved for each ECV. The specification of metrics places the entire enterprise on a much firmer foundation.

Achieving the metrics laid out in this response represents a significant challenge to the CEOS community and will require a degree of coordination and collaboration never achieved before. The continued development and implementation of the CEOS Virtual Constellations and Working Groups is vital to success. Close collaboration among CEOS, the GCOS program, WCRP satellite observational and data programs, and national climate programs is also vital.

CEOS will continue to develop, update, coordinate, and monitor the implementation of the action plans in this response. The Working Group on Climate will play a key role in these activities. Achievement of the goals outlined in these plans will provide the nations of the world with the data on climate change that are needed to make astute decisions on prevention, mitigation, and adaptation strategies.

Please visit the CEOS website www.ceos.org to download the full text of the *Response of the Committee on Earth Observation Satellites (CEOS) to the Global Climate Observing System Implementation Plan (GCOS IP-10)*