2015 Update of Actions in The Response of the Committee on Earth Observation Satellites (CEOS) to the Global Climate Observing System Implementation Plan 2010 (GCOS IP-10)

Developed by theCommittee on Earth Observation Satellites-Coordination Group for Meteorological Satellites (CEOS-CGMS) and submitted to the Global Climate Observing System (GCOS) in support of the United Nations Framework Convention on Climate Change (UNFCCC) Subsidiary Body on Scientific and Technological Advice (SBSTA)

10 May 2015

Committee on
Earth Observation Satellites

CGMS

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Executive Summary for the 2015 Update

The Global Climate Observing System (GCOS) has undertaken a periodic cycle of assessment of the adequacy of the observations and derived products for meeting requirements for monitoring climate and global change in support of the UN Framework Convention on Climate Change (UNFCCC). Following each assessment, GCOS has identified the needs for continuing, improving, and adding new observations and products which are then formulated into an implementation plan (IP). The CEOS–CGMS Working Group on Climate (WGClimate) is the body that responds to both the UNFCCC Subsidiary Body on Scientific and Technological Advice (UNFCCC-SBSTA) and GCOS by coordinating responses from Space Agencies on relevant actions. Figure 1 illustrates the relationship between the UNFCCC-SBSTA, GCOS and the WGClimate in their efforts to respond to user needs for climate and global change information. UNFCCC identifies broad needs, the GCOS identifies how well the observing systems are meeting those needs (via periodic status reports) and what is needed to maintain and improve the observing system (via periodic implementation plans containing consolidated requirements). The UNFCCC needs and GCOS requirements are updated periodically, about every 5–7 years.

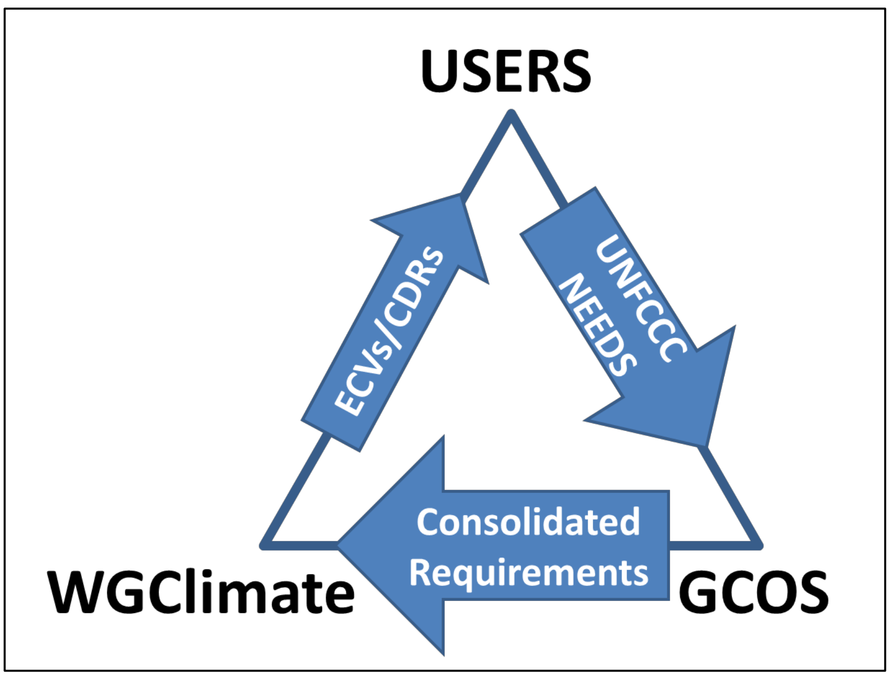


Figure 1. Relationship between the UN Framework Convention on Climate Change, the Global Climate Observing System, and the CEOS-CGMS Working Group on Climate.

The CEOS–CGMS WGClimate responds to both the UNFCCC and GCOS. The WGClimate works closely with GCOS and provides a major response to each GCOS implementation plan and status report as part of the cycle, as well as providing interim reporting to GCOS and the UNFCCC. The sequence of the current reporting cycle is illustrated in Figure 2.

The most recent cycle began in 2010 with the release of a GCOS implementation plan followed in 2011 with the release of a satellite supplement with specific sampling, accuracy, and stability requirements. In 2010-11, starting prior to the formation of the CEOS–CGMS WGClimate, CEOS formulated a response to the GCOS 2010 IP and satellite supplement led by the Climate Societal Benefits Area (SBA) lead. This activity was transitioned to the WGClimate in 2012 and delivered as a report to GCOS and UNFCCC at SBSTA-37 in December 2012. In preparation for the GCOS 2015 status report on the observing system, WGClimate has updated the 2012 document with this report detailing progress on promised deliverables and responses to all 47 Space Agency actions identified in the GCOS 2010 IP. The full planning, formulation of deliverables, final update to actions and deliverables providing input to the GCOS 2015 status report is illustrated in Figure 2.

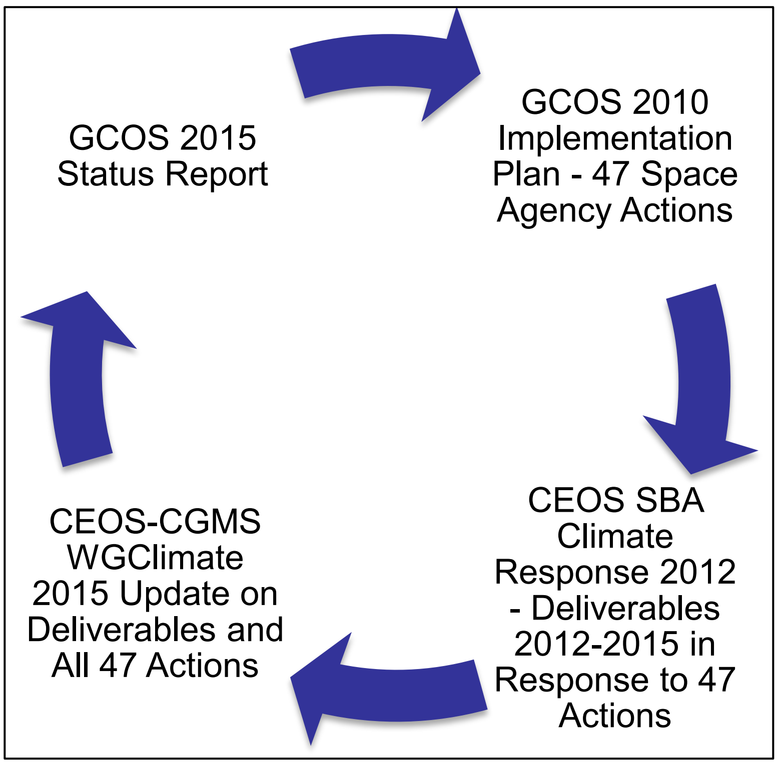


Figure 2. Cycle of Global Climate Observing System and CEOS-CGMS Working Group on Climate contributions.

For this update, WGClimate kept the original 2012 format and updated only Section 5 where each action was described in the original report. The 2015 Updates are added at the end of each of the 47 actions identified in that section. This provides the complete context for the updates. Since many factors influenced the ability of Space Agencies to respond to all the actions, some responses are more complete than others. In re-assessing all the GCOS actions identified for Space Agencies, a few were judged to be more properly addressed to other observing system operators and so no update was provided. The responses were provided by subject matter experts and WGClimate performed only minor editing. Also, the responses are intended as input to the 2015 GCOS assessment, so no attempt is made in this report to assess the overall status of Space Agency contributions to the climate observing system.

The 2015 update is also provided in a simple and perhaps more accessible format in Appendix 2. This appendix only lists each action from the GCOS 2010 IP followed by the 2015 response. This is provided for those who are simply looking for the direct link between action and response and do not need the historical context.

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

[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

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 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 (Appendix 1). 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.

In response to GCOS status report for 2015, the CEOS-CGMS Working Group on Climate revisited the actions identified in this original report. Experts or groups identified in the actions were contacted and their responses are listed at the end of each action in Section 5. These responses vary depending on the requested action, our ability to obtain input, and whether the nature of the action may have changed or have been overcome by events more recently. We have performed minimal editing to this input in order to retain the original wording and context of the subject matter experts who provided the input. Only these sections of the report have been update.

1. Introduction

1.1 Purpose of the Report

The purpose of this report is to provide a consolidated Space Agency response to actions from the Global Climate Observing System.

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

[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

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.

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

[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

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

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

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
- 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.

[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]."

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:

- 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)	Broadband radiances Spectrally-resolved solar irradiances	A.7.1 A.7.2

	Total and spectrally-resolved solar irradiance	Geostationary multispectral imager radiances	(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 variables[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,

[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

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 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 with 2015 Updates

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 2011 Satellite 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.

5.2 Role of CEOS Working Group on Climate

To coordinate, further develop, and oversee implementation of the GCOS IP-related Actions, in 2010, CEOS formed a Working Group on Climate (WGClimate). This Group:

- Reviews and assesses generation of FCDRs and derived ECV products supported by

CEOS Agencies;

- Reviews compliance of missions and products with the GCOS Climate Monitoring Principles;
- Identifies implementation teams for each product – ensures a coherent implementation plan exists for each and every satellite-based ECV product; and
- Works with the CEOS Virtual Constellations to ensure a coherent and consistent approach to the provision of climate records across their various topical areas.

5.3 The Atmosphere

5.3.1 Introduction

The GCOS IP-10 breaks down the climate system into three domains – atmosphere, oceans, and land – that interact with each other at their respective interfaces. The term "climate" can be defined as the mean and statistical properties of atmosphere near Earth's surface. Global temperatures are largely governed by the overall radiative properties of the atmosphere, while regional climates are controlled by transport properties of the atmosphere together with land surface and ocean interactions. The atmosphere plays a unique role in the climate system largely due to the growth and decay of weather systems and changes-in-state of water between snow, rain, cloud and vapor. Winds move heat, moisture and chemical species around rapidly. Cloud and water vapour feedbacks are major factors in determining the sensitivity of the climate system to forcings, such as from rising levels of greenhouse gases and from aerosols. Because natural modes of variability, such as El Niño and the North Atlantic Oscillation introduce short term (years) climate variations, it is vital to determine and understand such processes as they can obscure climate change detection.

The atmospheric ECVs for which satellite observations make a significant contribution are listed in Table 2 of Section 3.

5.3.2 Precipitation

Importance of this ECV

Precipitation affects water supplies, natural vegetation, crops, and tourism. Its variations can lead to environmental hazards in the form of droughts, floods, snow accumulations, hail, and ice. It affects the daily activities of humankind throughout the world. It is a key component of the Earth's hydrological cycle and, through its release of the latent heat of condensation as it forms, affects the thermal structure and the circulation of the atmosphere.

5.3.2.1 GCOS/CEOS Action A8; SS: A.2

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: 20-40M US$(for generation of climate products, assuming missions funded for other operational purposes) (Mainly by Annex-I Parties).

CEOS Entities:

- **CEOS Agency Leads**: NASA, JAXA
- **CEOS Agency Contributors**: NOAA, CSA, CNES, ISRO, INPE, EUMETSAT, ESA
- **CEOS Coordination Mechanisms**: Precipitation Virtual Constellation (PC-VC)

International Coordination Bodies: TBD

Associated Organizations: TBD

Specific Deliverable #1:

- The delivery is an initial calibration reference standard for the Global Precipitation Measurement (GPM) mission. The GPM concept centers on the deployment of a "Core" satellite carrying an advanced radar/radiometer system to measure precipitation from space and serve as a reference standard to unify precipitation measurements from a constellation of research and operational satellites.
    - To ensure the continuity of this constellation approach, NASA/JAXA will continue the Tropical Rainfall Measuring Mission (TRMM) that has both an imaging microwave radiometer, the TRMM Microwave Imager (TMI) and a Precipitation Radar (PR). This observatory is in a 35 deg. inclined orbit.
    - To extend and enhance the ability to intercalibrate constellation radiometers, NASA/JAXA will launch in 2014, the core observatory of the (GPM mission. This observatory will carry both an imaging microwave radiometer, GPM microwave imager (GMI) and a dual precipitation radar (DPR). This observatory will be in a 65 deg. inclined polar orbit.
    - JAXA is also contributing the Advanced Microwave Scanning Radiometer-2 (AMSR2) on the Global Change Observation Mission-Water (GCOM-W) to the CEOS PC-VC. Other agencies such as NOAA, EUMETSAT, CNES/ISRO will contribute microwave radiometers in both sun- and non-sun-synchoronous orbits (these will be mostly microwave sounders except for Megha-Tropiques, and Special Sensor Microwave Imager/Sounder [SSMI/S] radiometers). While these radiometers are launched and operated for their agencies own needs, they are contributed to the CEOS PC-VC (GPM era constellation) to be included for use in generating consistent precipitation products.
    - Radiometers in initial GPM-based PC constellation:
        - SSMI/S F16, F17, F18, F19, F20 microwave imagers containing both window channels and high-frequency sounding channels. Data are observed by the U.S. DOD satellites and archived at NOAA.
        - Advanced Microwave Sounding Unit (AMSU)-A/Microwave Humidity Sounder (MHS) sounders for precipitation using mainly the scattering channels. Provided by both NOAA and EUMETSAT.
        - Advanced Technology Microwave Sounder (ATMS) microwave sounders on both Suomi National Polar-orbiting Partnership (Suomi NPP) and Joint Polar Satellite System (JPSS) which for precipitation use mainly the scattering channels. Provided by both NOAA and EUMETSAT.

        - Microwave Analysis and Detection of Rain and Atmospheric Structures (MADRAS) microwave imager from the CNES/ISRO Megha-Tropiques tropical mission.
        - Sounder for Probing Vertical Profiles of Humidity (SAPHIR) microwave sounder from the CNES/ISRO Megha-Tropiques tropical mission. SAPHIR provides high-frequency sounding channels for precipitation measurements.
    - Precipitation Constellation Calibrating Observatory:
        - During the ad-hoc pre-GPM Precipitation Constellation (PC), the TRMM observatory provides the transfer standard for precipitation products for the PC. This was chosen because of the many match-up opportunities of the TRMM observatory and the polar-orbiting observatories in the constellation.
        - Beginning with the full PC that starts at the launch of the GPM core observatory in 2014, the GPM core observatory with its GMI and DPR will be the transfer standard used for creating consistent PC precipitation products. Once again the core observatory, like TRMM, provides many match-up opportunities with other observatories in the constellation.
- **PC characteristics for radiometers in the Constellation**
    - Each PC participating agency will provide a point of contact to the PC about its observatory, radiometer and its operation during the life of the mission.
    - Each PC participating agency will provide detailed information about the operation, geolocation and calibration of the radiometer that it is providing.
    - Each PC participating agency will completely characterize their radiometer and calibration and make such information available to other PC members as well as data users.
    - Each PC participating agency will ensure that incidence angle information is available for each pixel of each swath type for their instrument.
- **Characteristics of the PC transfer standard observatory**
    - Should contain well-calibrated radiometer with channels from 10 GHz through 183 GHz.
    - Should contain well-calibrated precipitation radar that represents the state of the art for characterizing rainfall.
    - Should be placed in a non-sun synchronous orbit to facilitate the number of match-up orbit crossovers between the reference observatory and other observatories in the constellation.
    - Both calibration and geo-location should be well characterized, tracked, published and the information publicly available.

Specific Deliverable #2:

- The deliverable is an instantaneous field of view level 1b calibrated, geolocated brightness temperature (T_b) product from each radiometer in the PC. The key to this delivery is the characterization of the inputs to the deliverable and the stability of the calibration and geolocation.

Specific Deliverable #3:

- The deliverable is a consistent PC instantaneous field of view inter-calibrated brightness temperature (T_c) product from each radiometer in the PC as established by applying the transfer standard established from the GPM core observatory.
- T_b products provided by contributors may be calibrated or geo-located according to the needs and requirements of the particular mission. To ensure consistency of PC brightness temperatures all brightness temperatures provided by contributors will be intercalibrated to meet the standards of this deliverable.

Specific Deliverable #4:

- The deliverable is a consistent PC precipitation product containing retrievals at instantaneous field of view based upon PC consistent inter-calibrated T_c. Also, to ensure consistency the retrieval will be based on a well-established Bayesian technique using a physically based *a priori* database constructed from the combined radiometer/radar measurement from the PC GPM core observatory. At latitudes for which the reference observatory measurements are not available, other physical measurements such as those from ground radars, cloud radars and other appropriate physical sources should be used before reverting to profiles generated from cloud resolving models.
- This precipitation retrieval will be performed for all radiometers in the PC. A similar retrieval based on a physically based *a priori* database will be made from imager and sounder radiometers. Appropriate retrievals will be made over ocean, land and coast.

Specific Deliverable #5:

- This deliverable provides a global monthly product containing PDF of precipitation intensity based on the instantaneous field of view (IFOV) products delivered in the previously listed deliverable #4.
- While this deliverable is not the end product of the ECV, it is the satellite component that appears most useful for further synthesis with other products.

Accuracy, stability, horizontal resolution, and vertical resolution

ECV: Precipitation	**GCOS/CEOS Action A8**				
	Property				
		Instantaneous FOV Tb	Instantaneous FOV inter-calibrated Tb	Precipitation rate (Instantaneous FOV)	Precipitation rate (Monthly)
Accuracy	Target	TBD	TBD	TBD	max(10% of daily totals; 0.1mm)
	Planned	TBD	0.3 K for each radiometer in the constellation with respect to the reference radiometer	TBD	TBD
Stability	Target	TBD	TBD	TBD	5% of daily totals (regional scale)
	Planned	1 K	TBD	TBD	TBD
Horizontal resolution (km)	Target	TBD	TBD	TBD	25
	Planned	5 (Precip. Radar)	25	25	100
Vertical resolution (km)	Target	TBD	N/A	N/A	N/A
	Planned	0.25 (Precip. Radar)	N/A	N/A	N/A

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

2015 Update

Specific Deliverable #1

- TRMM has continued to be operated; it is out of fuel and will be passivized in early 2015 when its orbit decays to a set altitude (325 km). The TMI is operating continuously, while the radar is only available when the altitude is in set ranges.
- GPM was launched into a 65° orbit on 27 February 2014 (UTC), and Day-1 GMI and DPR products were released in stages through the summer.
- The initial GPM-era constellation consists of microwave imagers (DMSP F15 SSMI [limited]; DMSP F16, F17, F18, and F19 SSMIS; TRMM TMI; GCOM-W1 AMSR2; GPM GMI) and microwave sounders (NOAA-18, NOAA-19, Metop-A, and Metop-B MHS; Megha-Tropiques SAPHIR; SNPP ATMS).
- The pre-GPM PC calibrator was the TRMM observatory; it is planned that intercalibration of the TRMM and GPM observatories will allow the entire TRMM-GPM era to be treated as a

continuous record, a long time series that is now viewed as critical for the long-term records demanded for societal applications, including climate studies.

- Upon reflection, "completely characterize" seems unachievable for sensors; "carefully" is a reasonable standard that agencies strive to achieve.

Specific Deliverable #2

The satellite operators work through GSICS to ensure calibration and geolocation at Level 1b.

Specific Deliverable #3

The GPM project's XCal Team developed and maintains intercalibrations of all radiometers to the Core Observatory reference at Level 1c.

Specific Deliverable #4

GPM is developing a physically based Bayesian retrieval system that can be applied to both imagers and sounders, GPROF2014, which is designed to be useful over land, coast, ocean, and frozen surfaces. Independently, NOAA is pursuing a more assimilation-like approach that applies to both imagers and sounders, MiRS.

Specific Deliverable #5

The output of GPROF2014 applied to all the microwave sensors in the constellation is freely available as individual satellite orbits at Level 2 – IFOVs in the original scan/footprint coordinates.

Additional Comments

1. Computations of the precipitation ECV rest not only on the microwave constellation currently considered the CEOS-VPC, but also on the geosynchronous constellation that provides increasingly rich multi-spectral data on relatively fine time intervals. As such, "the constellation" the community needs really encompasses both sets of satellites.
2. The future of the microwave constellation (and even the Indian Ocean segment of the geo-constellation) is open to question. It takes a decade or more to carry a satellite from concept to launch, so it seems essential to have a planning activity as part of the 5-year plan. One

can't open discussions at the end of one 5-year period and assume that satellites will appear to fill the need as legacy satellites age off of the system.

3. The current statement on the necessary number of microwave constellation satellites is that we need the time between observations to be no more than 3 hours. That's not an average, that's the maximum. The current uncoordinated collection of satellites makes it hard to achieve this, but we should go for some standard like "75% of gaps be <3 hours".

Reference

Hou, A. Y., R. K. Kakar, S. Neeck, A. A. Azarbarzin, C. D. Kummerow, M. Kojima, R. Oki, K. Nakamura, and T. Iguchi, 2014: The Global Precipitation Measurement Mission. *Bull. Amer. Meteor. Soc.*, **95**, 701–722, doi:10.1175/BAMS-D-13-00164.1

5.3.3 Surface Wind Speed and Direction

Importance of this ECV

Ocean surface wind is a major forcing mechanism for the Earth's oceans and an important climate variable in its own right. It drives ocean currents that transport heat horizontally and induces turbulent eddy, upwelling, and downwelling processes that transfer heat vertically in the oceans. It influences the transfer of heat, moisture, gases, and particles between the ocean and atmosphere. Winds are also the dominant destructive force in hurricanes through their direct effects and the high waves, storm surges, and coastal flooding they produce.

5.3.3.1 GCOS/CEOS Action A11; SS: A.1

Action: Ensure continuous generation of wind-related products from AM and PM satellite scatterometers or equivalent observations.
Who: Space agencies.
Time-Frame: Continuous.
Performance Indicator: Long-term satellite observations of surface winds every six hours.
Annual Cost Implications: 1-10M US$ (Mainly by Annex-I Parties).

CEOS Entities:

- **CEOS Agency Leads:** NOAA, EUMETSAT, ISRO
- **CEOS Agency Contributors**: TBD
- **CEOS Coordination Mechanisms:** Ocean Surface Vector Wind Virtual Constellation (OSVW-VC)

International Coordination Bodies: TBD

Associated Organizations: TBD

Specific Deliverable

- The CEOS OSVW-VC will provide wind-related products from AM and PM satellite scatterometers or equivalent observations.

Accuracy, stability, horizontal resolution, and vertical resolution

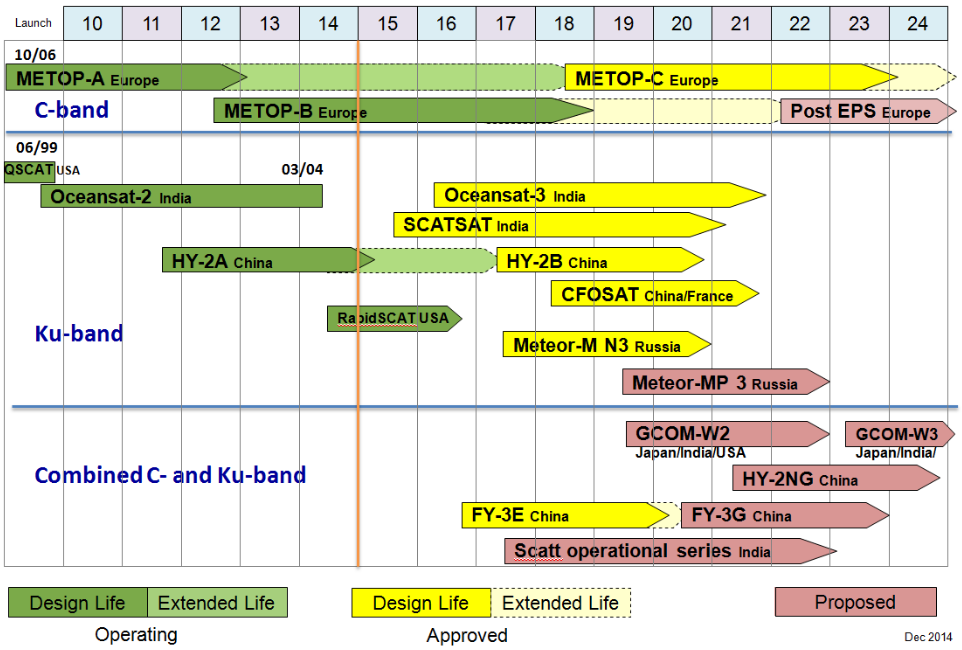
ECV: Surface wind speed and direction	**GCOS/CEOS Action A11**	
	Property	
	Surface wind	
Accuracy	Target	0.5m/s and mean quadratic statistics to 10% of the locally prevailing mean wind speed, for speeds >20m/s
	Planned	TBD
Stability (/decade)	Target	0.1 m/s
	Planned	TBD
Horizontal resolution (km)	Target	10 km
	Planned	TBD

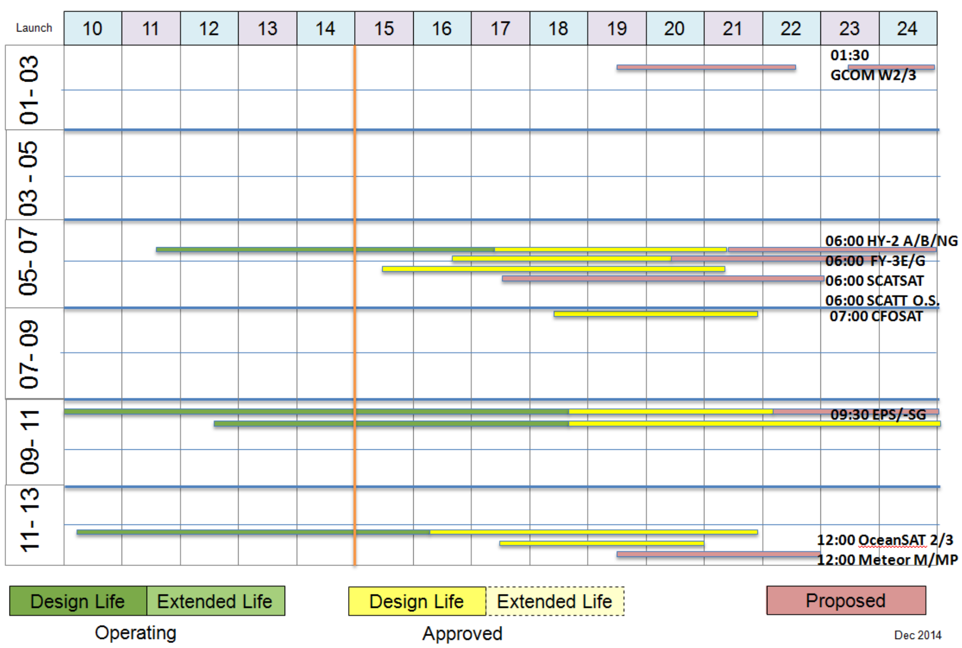
Planned activities/time frames to meet deliverables (2011 – 2015)

- Calibration and validation of each spaceborne observing system contributing to the OSVW-VC
- The definition of mutually agreed format(s) and inter-calibrated data product(s)
- Easy access to selected subsets of the resulting data products
- Harmonization of launches and orbits to optimize coverage in space and time
- Development and demonstration of systems capable of collecting improved observations

2015 Update

NASA’s International Space Station Rapid Scatterometer, or ISS–RapidScat, is the first near-global scientific Earth-observing climate instrument specifically designed and developed to operate from the exterior of the space station. The experimental mission will measure near-surface ocean wind speed and direction in Earth’s low and mid-latitudes in any kind of weather except heavy rain. ISS-RapidScat joins in orbit the EUMETSAT ASCAT, which is in morning polar orbit as of April 2015. Calibration and validation activities as well as data acess activities are being coordinated by the CEOS ocean surface vector wind virtual constellation (OSVW-VC - http://ceos.org/ourwork/virtual-constellations/osvw/). Space agency plans for ocean surface vector wind instrument frequency coverage and spatial sampling are shown below.





5.3.4 Upper-air Wind Speed and Direction; SS: A.4

Importance of this ECV

Upper-air wind is a basic element of the climate system that influences many other variables. It is responsible for the transports of heat, moisture, and momentum in the atmosphere. By transporting heat from equatorial regions to polar areas, the wind field reduces the equator to pole temperature gradient that would result from the excess solar heating of low latitudes.

Satellite Supplement Product A.4
There is no specific action in GCOS IP-10, but the Satellite Supplement includes the following target requirements listed as Product A.4 Upper air wind retrievals

ECV: Upper air wind	GCOS/CEOS Action	
	Property	
	Upper air wind	
Accuracy	Target	20 m/s, 20 degrees
	Planned	TBD
Stability (/decade)	Target	0.5 m/s, 5 degrees
	Planned	TBD
Horizontal resolution (km)	Target	10
	Planned	TBD
Vertical resolution (km)	Target	0.5
	Planned	TBD

Upper air wind speed and direction are obtained primarily from geostationary satellites by tracking the motion of clouds or moisture features in visible and infrared images over time. This technique is also applied to polar orbiting satellites in the arctic regions where there are short revisit times. The WMO SCOPE-CM program includes a coordinated effort to reprocess geostationary winds. In the near future, ESA's Atmospheric Dynamics Mission Aeolus (ADM-Aeolus) – scheduled for launch in 2014 – will provide lidar wind profiles with radiosonde-like quality wind speed and direction data.

The complete CEOS response to this action is under development.

2015 Update

A collaborative project within the Sustained and coordinated processing of Environmental Satellite data for Climate Monitoring (SCOPE-CM) is coordinating re-processing of atmospheric motion vectors (AVMs). Please visit the web site of this project for details: http://www.scope-cm.org/wpcms/wp-content/uploads/2014/01/SCM_10_AMV_geo_leo.pdf)

5.3.5 Climate Calibration Mission

Importance of this ECV
Current long-term climate data records are based mainly on the observations of the operational satellite systems. These satellites are designed primarily to provide measurements for short-term weather and environmental prediction. Instrument calibrations lack traceability to International Standards (SI) units, sensors degrade in orbit, and long term data sets must be stitched together from a series of overlapping satellite observations. A climate calibration mission would place in space a series of highly accurate benchmark instruments to measure with high spectral resolution the energy reflected and emitted by the Earth. These instruments would provide reliable long term records of climate forcings, responses, and feedbacks to monitor climate change. The

benchmark instruments would also constitute a reference standard, or calibration observatory, in space to calibrate other environmental satellite sensors—for example, the sensors on operational weather satellites—that are not as well calibrated.

5.3.5.1 GCOS/CEOS Action A19; SS: N/A

Action: Implement and evaluate a satellite climate calibration mission, *e.g.*, CLARREO.
Who: Space agencies (*e.g.*, NOAA, NASA, etc).
Time-Frame: Ongoing.
Performance Indicator: Improved quality of satellite radiance data for climate monitoring.
Annual Cost Implications: 100-300M US$ (Mainly by Annex-I Parties).

CEOS Entities:
- **CEOS Agency Leads:** NASA
- **CEOS Agency Contributors:** ESA, UKSA (supporting NPL)
- **CEOS Coordination Mechanisms:** TBD

International Coordination Bodies: WMO-Global Space-based Inter-Calibration System (GSICS), GEO, Quality Assurance for Earth Observations (QA4EO) initiative, International Bureau of Weights and Measures (BIPM)

Associated Organizations: TBD

Specific Deliverable #1:
- Highly accurate, global, SI-traceable on-orbit decadal change observations sensitive to the most critical, but least understood, climate forcings, responses, and feedbacks, including:
- Infrared (IR) spectra to infer temperature and water vapor feedbacks, cloud feedbacks, and decadal change of temperature profiles, water vapor profiles, clouds, and greenhouse gas radiative effects
- Reflected solar (RS) spectra to infer cloud feedbacks, snow/ice albedo feedbacks, and decadal change of clouds, radiative fluxes, aerosols, snow cover, sea ice, land use
- Global Navigation Satellite System Radio Occultation (GNSS-RO) observations to infer decadal change of temperature profiles

Specific Deliverable #2
- IR and RS spectra that are matched in time, space, and angle with data from broadband Earth radiation budget (*e.g*., Clouds and Earth's Radiant Energy System [CERES]), operational IR sounders (*e.g*., Cross-track Infrared Sounder [CrIS], Infrared Atmospheric Sounding Interferometer [IASI]), and low-Earth orbiting (LEO) and geostationary (GEO) imagers (*e.g.*, Visible/Infrared Imager/Radiometer Suite [VIIRS], Advanced Very High Resolution Radiometer [AVHRR], Sentinel 2 and 3) for use as a reference intercalibration source. Implemented systems may also provide reference calibrations for some CEOS VCs and also support other non-space observing systems.

Accuracy, stability, horizontal resolution, and vertical resolution

- For deliverables #1 and #2:

ECV: Climate calibration mission	**GCOS/CEOS Action A19**			
		Property		
		IR	Reflected solar	Radio occultation
Accuracy	Target	0.1 K	0.3%	0.03%
	Planned	0.1	0.3	0.03
Stability (/decade)	Target	0.1 K		
	Planned	0.1		
Horizontal resolution	Target			
	Planned	25 – 100 km	0.5 km	Occultation
Vertical resolution	Target	N/A	N/A	?
	Planned	N/A	N/A	?

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

NASA conducted Pre-Phase A science and mission planning for the Climate Abosulte Radiance and Refractivity Observatory (CLARREO) from 2008-2010. The mission successfully completed its Mission Concept Review (MCR) in November of 2010, and had planned to move into Phase A early in 2011. Following the release of the President's FY12 budget for NASA, the funding profile for CLARREO was reduced. The new budget guidance was for the CLARREO mission to enter an extended Pre-Phase A and to examine other ways to achieve some portion of the CLARREO science in the near term through alternative mission concepts, instruments of opportunity or aircraft; international collaboration, interagency collaboration, or other mission implementations. During 2011-2015, the CLARREO team will advance the science and seek to identify options for achieving the full CLARREO objectives in the future. No launch readiness date has been set for CLARREO.

Planning for independent measures in the RS (such as Traceable Radiometry Underpinning Terrestrial-and-Helio-Studies [TRUTHS]) and in the IR should occur early in this time frame in order to coordinate measurement strategies and operations.

The CLARREO team should coordinate planning for reference intercalibration with international groups such as the GSICS and the CEOS Working Group on Calibration and Validation (WGCV) and in particular consider uncertainties achievable and any operational infrastructure that might need to be established to enable implementation.

Planning for research-to-operations transition of these measurements should occur between NASA and NOAA to ensure continuity and other CEOS agencies as appropriate. More information of the current activities can be found:

CLARREO: http://clarreo.larc.nasa.gov/

TRUTHS: http://www.npl.co.uk/TRUTHS

2015 Update

The lack of a GCOS Climate Calibration Mission remains a serious gap in the GCOS climate observing system. No space agency has yet started such a mission although the U.S. (NASA) and the UK (NPL) has invested substantially in pre-phase A science, instrument, and mission studies relevant to such a mission. A summary of the status is given below.

In 2007, the U.S. National Research Council (NRC, 2007) recommended CLARREO (Climate Absolute Radiance and Refractivity Observatory) as a NASA space-based mission with goals consistent with the GCOS Climate Calibration Mission. The CLARREO mission includes a reflected solar spectrometer (320 to 2300 nm spectral coverage, 4 nm spectral sampling, and an SI traceable accuracy requirement of 0.3% of the Earth's mean reflectance at 95% confidence). It also includes an infrared spectrometer (200 to 2000 cm-1 spectral coverage, 0.5 cm-1 spectral resolution, and an SI traceable accuracy requirement of 0.07K at 95% confidence). Both spectrometers are designed to serve as in orbit calibration references for space based instruments that include spectrometers, band pass radiometers and broadband radiation radiometers (Wielicki et al. 2013 and references therein). These spectrometers are also designed to provide reflected solar and infrared spectra capable of serving as spectral fingerprints of climate change (e.g. Feldman et al. 2011, Huang et al., 2010).

The WMO GSICS (Global Space Based Intercalibration System) has called for the CLARREO mission (or equivalent) to provide reference spectrometers for GSICS intercalibration of both low earth orbit and geostationary orbit instruments (Goldberg et al., 2011).

Extensive pre-phase A study has been done on the CLARREO mission science, instruments and mission leading to a successful Mission Concept Review in November, 2010 An overview of these studies and the mission design can be found in Wielicki et al. 2013 as well as the CLARREO mission home page at clarreo.larc.nasa.gov). In early 2011, however, NASA's Earth Science budget was reduced by roughly $1.5 billion dollars, leading to a delay of the CLARREO mission with a current launch date of no earlier than 2023. The mission continues pre-phase A studies focusing on reducing instrument size, cost, and risk. These studies are also focused on further clarifying the mission science requirements and understanding analysis algorithms for reference intercalibration of sensors as well as uncertainties in spectral fingerprinting. Efforts are underway to explore possible international collaboration on this mission, with either the UK or India.

In the UK, the TRUTHS mission (Traceable Radiometry Underpinning Terrestrial- and Helio-Studies) was proposed to the ESA Explorer Earth Explorer-8 announcement but was not selected for flight due to cost limitations. TRUTHS provides an alternative method to achieve the reflected solar portion of the GCOS 5.3.5 Climate Calibration Mission (Fox et al., 2011, and http://www.npl.co.uk/TRUTHS). Individual elements of the CLARREO mission (infrared or reflected solar) have also been proposed to NASA's small Venture class missions, but are not a good fit to the cost caps and programmatic design of the Venture opportunity. Neither the NASA Venture program nor the ESA Earth Explorer are designed for long term climate monitoring mission goals.

The CLARREO mission studies to date have been used to estimate the world economic value of advanced much higher accuracy climate observations, resulting in an estimate of $12 Trillion U.S. dollars in Net Present Value (3% discount rate) (Cooke et al. 2014). This value suggests a return on investment of roughly 50 to 1 if investments in climate observations were tripled from current levels to allow a more rigorous and more complete international climate observing system.

Efforts continue in the U.S. and UK to accelerate launch of a Climate Calibration Observatory, but none of these efforts has yet advanced beyond pre-phase A studies, primarily due to funding limitations in UK, ESA and NASA budgets. The technologies for both the CLARREO and TRUTHS missions have been advanced to the TRL-6 levels required for mission starts. Demonstration laboratory instruments have been built at both NASA Langley and University of Wisconsin for the infrared interferometer, as well as at both NASA Goddard Space Flight Center and University of Colorado LASP in order to further reduce mission risk and cost. The U.S. National Institute of Standards and Technology (NIST) has been a partner in calibration verification of these new instrument designs. As part of this effort, NIST has been developing improved SI standards for wavelengths between 1000 and 2500 nm in the reflected solar spectrum and between 100 and 600 cm-1 in the infrared spectrum.

References:

Cooke, R., B. A. Wielicki, D. F. Young, and M. G. Mlynczak, 2014: Value of information for climate observing systems. *Environ. Syst. Decis.*, **34**, 98–109, doi:10.1007/s10669-013-9451-8.

Feldman, D. R., C. A. Algieri, W. D. Collins, Y. L. Roberts, and P. A. Pilewskie, 2011: Simulation studies for the detection of changes in broadband albedo and shortwave nadir reflectance spectra under a climate change scenario. *J. Geophys. Res. Atmos.*, **116**, D24103, doi:10.1029/2011JD016407.

Fox, N., A. Kaisser-Weiss, W. Schmutz, K. Thome, D. Young, B. Wielicki, R. Winkler, and E. Woolliams, 2011: Accurate radiometry from space: An essential tool for climate studies. *Philos. Trans. Roy. Soc.*, **369A**, 4028–4063, doi:10.1098/rsta.2011.0246.

Goldberg, M., and Coauthors, 2011: The Global Space-Based Inter-Calibration System (GSICS). *Bull. Amer. Meteor. Soc.*, **92**, 467–475.

Huang, Y., S. Leroy, P. J. Gero, J. Dykema, and J. Anderson, 2010: Separation of longwave climate feedbacks from spectral observations. *J. Geophys. Res. Atmos.*, **115**, D07104, doi:10.1029/2009JD012766.

NRC, 2007: Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond. National Academy Press, 428 pp.

Wielicki, B. A., and Coauthors, 2013: Climate Absolute Radiance and Refractivity Observatory (CLARREO): Achieving climate change absolute accuracy in orbit. *Bull. Amer. Meteor. Soc.*, **94**, 1519–1539.

5.3.6 Upper Air Temperature

Importance of this ECV

Atmospheric temperature is the most widely tracked response variable in the climate system. Climate models predict that anthropogenically caused greenhouse warming would be amplified in the mid-to upper- troposphere but would change to cooling in the stratosphere. Thus, upper air temperatures are a key dataset for detection and attribution of tropospheric and stratospheric climate change.

5.3.6.1 GCOS/CEOS Action A20; SS: A.3.2

Action: Ensure the continued derivation of MSU-like radiance data, and establish FCDRs from the high-resolution IR sounders, following the GCMPs.
Who: Space agencies.
Time-Frame: Continuing.
Performance Indicator: Quality and quantity of data; availability of data and products.
Annual Cost Implications: 1-10M US$ (for generation of datasets, assuming missions, including overlap and launch-on-failure policies, are funded for other operational purposes) (Mainly by Annex-I Parties).

Microwave Sounding Unit (MSU)-like radiance and high spectral resolution infrared radiance observations will be sustained into the future by satellite agencies. In particular, NOAA will provide microwave radiances from the ATMS instrument and high resolution IR radiances from CrIS. EUMETSAT will continue to fly AMSU and IASI. Both the NOAA and EUMETSAT programs will sustain these types of measurements well into the 2030's and beyond. Also, CMA plans to fly advanced microwave and infrared sounders on their future polar orbiting satellites. Future geostationary satellites from a number of operational satellite agencies will include high resolution sounders. Both advanced microwave and infrared sounders provide accurate temperature and water vapor profiles with vertical resolutions between 1 – 2 km from the infrared and 3-5 km from the microwave instruments. Infrared measurements from IASI, CrIS and AIRS have been shown to be very accurate with differences between instruments well within 0.1K, which meets FCDR requirements. This is in contrast to microwave observations which require intercalibration and considerably more effort to create FCDRs. Thus, this CEOS response is focused on efforts to create FCDRs from microwave radiance data.

CEOS Entities:

- **CEOS Agency Leads:** NOAA
- **CEOS Agency Contributors:** EUMETSAT, NASA, CMA
- **CEOS Coordination Mechanisms:** TBD

International Coordination Bodies: CGMS, GSICS

Associated Organizations: Remote Sensing Systems (RSS), University of Alabama at Huntsville (UAH), University of Washington (UW), National Center for Atmospheric Research (NCAR)

Specific Deliverable #1
The deliverables are the merged deep atmospheric layer temperatures from different MSU-like channel observations on consecutive satellites from 1979 to the future.

Specific Deliverable #2
The deliverables are inter-satellite calibrated radiance FCDR from AMSU-A, ATMS and Microwave Temperature Sounder (MWTS) temperature sounding channels using the Simultaneous Nadir Overpass (SNO) method.

Accuracy, stability, horizontal resolution, and vertical resolution

ECV: Upper air temperature	**GCOS/CEOS Action A20**	
	Property (monthly values)	
		Layer temperatures
Accuracy (K)	Target	0.2
	Planned	0.5
Stability (K/decade)	Target	0.02
	Planned	0.05
Horizontal resolution (km)	Target	100
	Planned	100
Vertical resolution (km)	Target	5
	Planned	5

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

For Deliverable #1
NOAA team:

- Develop AMSU-only layer temperature time series from 1998 to present for channels 4-14 in the time frame 2011-2012.
- Develop merged SSU/AMSU layer temperatures from 1978 to present for the middle to top stratosphere in the time frame 2011-2013.
- Extend the existing MSU/AMSU and the planned AMSU-only and SSU/AMSU time series to include ATMS observations when the ATMS data are accumulated for a few years. The time frame for this activity is 2014-2015.
- Develop temperatures of lower-troposphere from MSU/AMSU/ATMS observations from 1979 to present in the time frame of 2012-2013.
- Validate/compare layer temperature products against Radiosonde Observation (Upper Air Observation (RAOB), Global Positioning System Radio Occultation (GPSRO), Lidar, Atmospheric Radiation Measurement (ARM), Atmospheric Infrared Sounder (AIRS),and reanalyses etc. as appropriate throughout the development of the temperature time series.

UAH team:

- Develop means to continue a backward-compatible product line (to 1979) that represents homogeneous time series of bulk tropospheric and stratospheric temperatures. This will include the full characterization of the diurnal cycle for the AMSU and follow-on microwave sensors. A key development here is the use of the non-drifting AMSU on AQUA to serve as an anchor relative to spacecraft that are drifting. Research on new challenges due to channel drifts, gaps, failures, etc.

RSS team:

- Develop AMSU-only layer temperature time series from 1998 to present from AMSU channels 10-14. These will be delivered in early 2012
- Develop weighted combination of AMSU channels 9-14 that match the vertical weighting functions for SSU channels 25 and 26. SSU channel 27 is impossible to match using AMSU measurements.
- Continue routine generation of MSU/AMSU products for temperature lower troposphere (TLT), temperature middle troposphere (TMT), temperature troposphere/stratosphere (TTS) and temperature lower stratosphere (TLS).
- Develop an "atmospheric only" lower tropospheric product from AMSU channels 3, 4, and 5, plus ancillary data to provide a second source of lower tropospheric temperatures that does not require the extrapolation procedure that is used to produce TLT.

Inter-Comparison/Reconciliation:

- In view of the large discrepancies in temperature trends among three teams (maximum of 0.1 K/Decade, which are much larger than the GCOS stability requirement of 0.02 K/decade), efforts will be made to understand and reconcile/reduce these discrepancies.

For Deliverable #2

- SNO inter-calibrated AMSU-A radiances onboard NOAA-15 through NOAA-19, Metop-A, and NASA Aqua will be delivered in 2013
- SNO inter-calibrated AMSU-A/ATMS radiances will be delivered in 2015. The NPP mission was launched in October 2011. AMSU/ATMS inter-calibration will begin in 2014 when ATMS observations are accumulated with sufficient length.

2015 update

Derived MSU-like radiance data include two types of products: recalibrated/inter-calibrated swath radiance FCDRs and channel-based atmospheric layer mean temperature TCDRs derived from averaging swath radiances over grid cells. Observations from four microwave and infrared temperature sounders including MSU (microwave), AMSU (microwave), SSU (infrared), and ATMS (microwave) onboard historical and currently operating polar orbiting satellites from NOAA, NASA EOS, and European MetOp were used in these developments. Three organizations were involved in developing the products in which NOAA is a lead agency developing both MSU-like FCDRs and TCDRs. The other two agencies, UAH and RSS, focused on deriving TCDRs. Some products were developed by all three agencies which are not only used for climate change monitoring and investigations, but also for mutual validation for improvement of merging algorithms. On the other hand, some other products (e.g., SSU related products) may have been developed by only one agency. Specific deliverables were proposed in the implementation plans for the period of 2010-2015 including both atmospheric temperature TCDRs (specific deliverable #1) radiance FCDRs (specific deliverable #2) development. Many accomplishments were achieved during this period and below are a summary based on proposed products.

For Specific Deliverable #1

- AMSU-only layer temperature time series from 1998 to present for channels 4-14 from the lower-troposphere to the upper stratosphere: NOAA has completed such a data set for all proposed AMSU-A channels 4-14 from 1998 to 2011. Details on merging algorithms and dataset characteristics can be seen from the publication on this dataset in Wang and Zou (2014). RSS has completed the AMSU-A stratospheric channels 9-14.
- Merged SSU/AMSU layer temperatures for the middle to upper stratospheres from 1978 to present: The raw SSU data contained multiple drifting issues that were not well studied and documented during the early stage of the satellite operations. NOAA has recently made a big effort in addressing SSU issues and to develop SSU-only temperature time series. The release of the first version of the NOAA SSU temperature climate data record in 2012 sparked community debate on the stratospheric temperature trends (Thompson et al. 2012). To address community concerns, NOAA further developed a recalibrated SSU swath radiance FCDR and an updated version of the SSU temperature dataset based on improved calibration and bias correction schemes. The new radiance FCDR and the updated SSU temperature datasets are described in details in Zou et al. (2014).

Since it depends on maturity of both the SSU-only and AMSU-only datasets, merging of the SSU and AMSU at NOAA has been delayed due to the SSU work, but it will be reassumed shortly after the SSU dataset reaches maturity. Meanwhile, RSS developed a weighted combination of AMSU channels 9-14 that matches the vertical weighting functions for SSU channels 1 and the data was put on their website.

- Extend the MSU/AMSU/SSU time series to ATMS: Actual merging with ATMS has not started yet since the ATMS observations are still short. Matching algorithms between AMSU and ATMS for consistent scanning geometries have been investigated at NOAA (Zou and Weng et al. 2014). The algorithm will be used for investigating inter-satellite biases between AMSU and ATMS which will be a basis for future merging between the different instrument observations.
- Lower-tropospheric temperature: NOAA developed AMSU-only channel 4 temperature time series which measures the layer mean temperatures of the lower-troposphere. This temperature time series were derived from AMSU-A channel 4 near nadir observations and thus they are not affected by the orbital-decay as in the MSU temperature of lower-troposphere (TLT) when derived from the MSU/AMSU near limb observations. In addition, temperatures derived from near nadir observations contain much smaller noise than the MSU limb-based TLT dataset. RSS is also developing AMSU-A channel 4 temperature product.
- Merged MSU/AMSU temperatures of mid-troposphere, upper-troposphere and lower-stratosphere: NOAA developed version 3.0 of these products which used MSU satellites from TIROS-N through NOAA-14 and AMSU satellites from NOAA-15 though NOAA-18, NASA AQUA, and European MetOp-A. The products used SNO calibrated swath radiances and contained improved diurnal, limb, and channel frequency corrections. They are updated regularly every month for climate change monitoring at NOAA.

RSS is currently developing Version 4.0 of these datasets. The differences from their V3.3 (the current version and is routinely generated) are as follows:

a. All data is sourced from NOAA's CLASS system. (V3.3 and earlier had some MSU data obtained from other sources, and thus not strictly traceable.)
b. Improved satellite height for some of the early MSU satellites.
c. Improved diurnal adjustments. The previously used model-based adjustments are slightly tuned to remove any remaining trends in intersatellite differences.
d. Improved merging techniques. Intersatellite offsets are calculated separately for land and ocean scenes to decrease the effects of errors in the diurnal adjustment on ocean scenes.
e. Their current product is based on all MSU satellites, and AMSU measurements from NOAA-15, NOAA-18, METOP-A, and AQUA. RSS anticipates releasing V4 during the first half of 2015.

UAH is developing version 6.0 of these products for which they have: (a) recharacterized the diurnal cycle by simply calculating the drift of one sensor relative to a non-drifting sensor at the /*grid*/*month*/*local time*/ level (e.g. NOAA-15 vs. AQUA for a.m. orbiters), (b) generated a multi-channel AMSU product that mimics the weighting functions of MSU channels 2 and 4 at the footprint level and (c) generated an AMSU swath result that is spatially consistent (i.e. backward compatible) with the MSU swath.

- Validate/compare layer temperature products against Radiosonde Observation (Upper Air Observation (RAOB), Global Positioning System Radio Occultation (GPSRO), Lidar, Atmospheric Radiation Measurement (ARM), Atmospheric Infrared Sounder (AIRS), and reanalyses etc. as appropriate throughout the development of the temperature time series: Inter-comparison studies for the MSU-like satellite data with other observations were conducted at all three organizations which resulted in multiple peer-reviewed publications such as Powell, et al. (2013, NOAA), Wang and Zou (2013, NOAA), He et al. (2013, NOAA), and Mears (2012, RSS). Details on comparison results can be found from these publications.

For Specific Deliverable #2

- SNO inter-calibrated AMSU-A radiances onboard NOAA-15 through NOAA-18, Metop- A, and NASA Aqua: The work was completed at NOAA and a whole set of SNO inter-calibrated swath radiances for channels 4-11 on 6 AMSU satellites were transitioned to NOAA/NCDC for archiving and operational distribution. The inter-calibration is currently routinely conducted every month which adding the newly inter-calibrated radiances for the month to the existing datasets.
- SNO inter-calibrated AMSU-A/ATMS radiances: The work has not started yet due to funding limit.
- Recalibration/inter-calibration of SSU swath radiances were recently completed by NOAA team (Zou et al. 2014). The recalibration took into account the space view anomalies and removed artificial satellite biases. The recalibrated radiances were put on the NOAA/STAR website which are expected to improve climate reanalyses in the upper stratosphere.

References:

He, W., C. Zou, and H. Chen, 2014: Validation of AMSU-A measurements from two different calibrations in the lower stratosphere using COSMIC radio occultation data. *Chin. Sci. Bull.*, **59**, 1159–1166, doi:10.1007/s11434-014-0125-9.

Mears, C. A., F. J. Wentz, and P. W. Thorne, 2012: Assessing the value of microwave sounding unit-radiosonde comparisons in ascertaining errors in climate data records of tropospheric temperatures. *J. Geophys. Res. Atmos.*, **117**, D19103, doi:10.1029/2012JD017710.

Powell, A. M. Jr., J. Xu, C.-Z. Zou, and L. Zhao, 2013: Stratospheric and tropospheric SSU/MSU temperature trends and compared to reanalyses and IPCC CMIP5 simulations in 1979–2005. *Atmos. Chem. Phys. Discuss.*, **13**, 3957–3992, doi:10.5194/acpd-13-3957-2013.

Thompson, D. W. J., D. J. Seidel, W. J. Randel, C.-Z. Zou, A. H. Butler, R. Lin, C. Long, C. Mears, and A. Osso, 2012: The mystery of recent stratospheric temperature trends. *Nature*, **491**, 692–697, doi:10.1038/nature11579.

Wang, L, and C.-Z. Zou, 2013: Intercomparison of SSU temperature data records with Lidar, GPS RO, and MLS observations. *J. Geophy. Res. Atmos.*,**118**, 1747–1759, doi:10.1002/jgrd.50162.

Wang, W., and C.-Z. Zou, 2014: AMSU-A-only atmospheric temperature data records from the lower troposphere to the top of the stratosphere. *J. Atmos. Oceanic Technol.*, **31**, 808–825, doi:10.1175/JTECH-D-13-00134.1.

Zou, C.-Z., H. Qian, W. Wang, L. Wang, and C. Long, 2014: Recalibration and merging of SSU observations for stratospheric temperature trend studies. *J. Geophys. Res. Atmos.*, **119**, 13180–13205, doi:10.1002/2014JD021603.

Zou, X., F. Weng, Xiaolei Zou, Fuzhong Weng, and H. Yang, 2014: Connecting the time series of microwave sounding observations from AMSU to ATMS for long-term monitoring of climate. *J. Atmos. Oceanic Technol.*, **31**, 2206–2222, doi:10.1175/JTECH-D-13-00232.

5.3.6.2 GCOS/CEOS Action A21; SS: A.3.1

Action: Ensure the continuity of the constellation of GNSS RO satellites.
Who: Space agencies.
Time-Frame: Ongoing; replacement for current COSMIC constellation needs to be approved urgently to avoid or minimize a data gap.
Performance Indicator: Volume of data available and percentage of data exchanged.
Annual Cost Implications: 10-30M US$ (Mainly by Annex-I Parties).

CEOS Entities:

- **CEOS Agency Leads:** NOAA
- **CEOS Agency Contributors:** NASA, EUMETSAT
- **CEOS Coordination Mechanisms:** TBD

International Coordination Bodies: CGMS International Radio Occultation Working Group (IROWG)

Associated Organizations: TBD

Specific Deliverable(s)

- Continuity in GNSS Radio Occultation (RO) Atmospheric Profiles available for Near-Real-Time (NRT) use and Climate

Accuracy, stability, horizontal resolution, and vertical resolution

ECV: Upper air temperature	GCOS/CEOS Action A21		
	Property		
		Tropospheric Temperature	Stratospheric Temperature
Accuracy (K)	Target	0.5	0.5
	Planned	1	TBD
Stability (K/decade)	Target	0.05	0.05
	Planned	TBD	TBD
Horizontal resolution (km)	Target	25	TBD
	Planned	100s	100
Vertical resolution (km)	Target	1	2
	Planned	0.1 to 2	TBD

Key activities and time frames to meet deliverables (2011 – 2015)

- Build up a ground station network that assures data download from research satellites in NRT. Include low latitude stations for low inclination satellites.
- Support constellation of RO instruments; try to include RO instruments on all meteorological Low-Earth-Orbit satellites.
- Assure availability of GPS data in NRT (and extend this to Galileo / others once available).
- Build up RO processing / re-processing expertise for all missions at several centers worldwide to allow the generation of consistent data sets.

2015 Update

U.S. agencies and Taiwan have decided to move forward with a follow-on RO mission (called FORMOSAT-7/COSMIC-2) that will launch six satellites into low-inclination orbits in late 2015, and another six satellites into high-inclination orbits in early 2018. U.S. agencies, lead by the National Oceanic and Atmospheric Administration (NOAA) are now actively partnering with Taiwan's National Space Organization (NSPO) to execute the COSMIC-2 program. The Global Navigation Satellite System (GNSS) RO payload, named TGRS for TriG (Tri-GNSS) GNSS Radio-occultation System, is being developed by NASA's Jet Propulsion Laboratory (JPL) and will be capable of tracking up to 12,000 high-quality profiles per day after both constellations are fully deployed.

5.3.7 Cloud Properties

Importance of this ECV

Inadequate knowledge about what will happen to cloud feedbacks due to global warming is one of the major causes of uncertainty in model predictions of global climate change. High clouds heat the Earth by downward emission of infrared radiation and low clouds cool the Earth through reflection of solar radiation. On average, the cooling effect of clouds is greater than their heating effect. Even small changes in this balance have implications for the Earth's climate. The cloud ECV is actually a complex set of properties that need to be observed: Cloud amount, top pressure and temperature, optical depth, water path and effective particle radius.

5.3.7.1 GCOS/CEOS Action A23; SS: A.6. to A.6.6 (cloud amount, cloud top pressure, cloud top temperature, cloud optical depth, cloud water path, and cloud effective particle radius)

Action: Continue the climate data record of visible and infrared radiances, *e.g.,* from the International Satellite Cloud Climatology Project, and include additional data streams as they become available; pursue reprocessing as a continuous activity taking into account lessons learnt from preceding research.
Who: Space agencies, for processing.
Time-Frame: Continuous.
Performance Indicator: Long-term availability of global homogeneous data at high frequency.
Annual Cost Implications: 10-30M US$ (for generation of datasets and products) (Mainly by Annex-I Parties).

CEOS Entities:

- **CEOS Agency Leads:** NOAA
- **CEOS Agency Contributors:** EUMETSAT, NASA, ESA
- **CEOS Coordination Mechanisms:** TBD

International Coordination Bodies: Global Energy and Water Cycle Experiment (GEWEX) Data and Assessments Panel (GDAP), SCOPE-CM

Associated Organizations: TBD

Specific Deliverable(s)

- Reduced resolution, calibrated solar reflectances and infrared radiances, global ancillary products (atmospheric temperature-humidity, snow-sea ice cover), global cloud products at three space-time resolutions, documentation (including scientific basis) and quality assessments.

Accuracy, stability, horizontal resolution, and vertical resolution

ECV: Cloud Properties	**GCOS/CEOS Action A23**			
		Property		
		Amount	Mass	Vertical Extent
Accuracy	Target	0.01-0.05	25%	1.0 km
	Planned	7 %	10	0.5
Stability (%/decade)	Target	0.003-0.03	5	2
	Planned	1	1	1
Horizontal resolution (km)	Target	50	50	50
	Planned	10	10	10
Vertical resolution (km)	Target	TBD	TBD	TBD
	Planned	1.0	1.0	1.0

Key activities and time frames to meet deliverables (2011 – 2015)

- Revision of International Satellite Cloud Climatology Project (ISCCP) calibration and cloud retrieval based on latest research (January 2013)
- Complete re-processing of ISCCP at higher spatial resolution (March 2013)
- Complete re-processing of NOAA (Pathfinder Atmospheres-Extended [PATMOS-x]) and EUMETSAT (Satellite Application Facility on Climate Monitoring [CM-SAF]) AVHRR data products and thorough comparisons
- Generation of definitive NASA Earth Observing System (EOS) A-train cloud records (2002-2015)
- Identify sources of information that can improve performance of AVHRR-based cloud products in polar-regions
- The ESA Climate Change Initiative initiated a Cloud CCI Project to produce the full suite of GCOS cloud parameters.

2015 Update

- GSICS is providing operationally re-calibrated radiances of the infra-red (IR) and water-vapour (WV) channels of the geostationary satellites operated by the different space-agencies (NOAA, EUMETSAT, CNES, JMA, KMA, CMA, ...). Currently these re-calibrations are only provided for the near-real-time observations. The re-calibration is performed against infrared sounding instruments as a reference. The methods developed within GSICS serve as baseline for developing re-calibration method for SCOPE-CM. The target accuracy of the re-calibrated IR/WV brightness temperatures is 0.5 K.
- GSICS is developing methods to re-calibrate radiances from the visible (VIS) and near-infrared (NIR) channels. GSICS is assessing several re-calibration methods, such as the use of Deep Convective Clouds, Desert Targets, and Moon observations. Moreover, GSICS evaluates Simultaneous Nadir Overpass calibration methods using SCIAMACHY spectra or MODIS radiances. Contrary to the IR/WV methods there is not a single best method for the VIS/NIR re-calibration, making it necessary to combine methods. At first instance these re-

calibrations are only provided for the near-real-time observations. The methods developed within GSICS serve as baseline for developing re-calibration method for SCOPE-CM. The target accuracy and precision of the re-calibrated VIS/NIR radiances are 2–3%.

- The SCOPE-CM Inter-calibration of imager observations from time-series of geostationary satellites (IOGEO) project aims to generate a Fundamental Climate Data Record (FCDR) calibrated and quality-controlled geostationary sensor data (~1980 – date). The FCDR will contain VIS, IR, and WV channels of geostationary satellites. It is proposed to utilise the inter-calibration methods developed by GSICS to tie existing time series of satellite data to the best reference available in space. The calibration accuracy and precision will be evaluated by comparing re-calibrated radiances of the different geostationary satellites in overlap regions. The initial aim of this SCOPE-CM activity is that each participating space agencies (EUMETSAT, NOAA, JMA, CMA, IMD) provides FCDRs for their geostationary satellites at the native instrument resolution. The final aim is to provide a re-gridded (0.05x0.05 degrees) combined global (-70 to 70 degrees) data record (1982–date) at hourly resolution of inter-calibrated radiances including all participating geostationary satellites. Current status is that the participating space agencies are re-calibrating the IR and WV channels of their geostationary instruments. Next year, comparisons of re-calibrated radiances will be made in overlap regions. The re-calibration of the VIS and NIR channels is planned to start in 2016/2017.
- The SCOPE-CM ISCCP project:
    - Reprocessing and stewardship of the ISCCP H-Series production is underway. The major activities thus far have focused on running and properly testing the ISCCP H-series code package. Our QC activities currently use an automated QC procedure combined with visual inspections of GAC and B1U data to eliminate corrupt data from production.
    - Test production of the base period (1983-2009) has begun and HGM products for years 2009-2007 are currently being evaluated via visual inspection and statistical analysis
    - A sample of H-Series data products for 2007 have been distributed to various users/partners within the scientific community. The purpose of this activity is to solicit external feedback on the ISCCP H-Series products and to alert users of its upcoming availability.
    - Updates to the code package continue to be delivered by the PI to fix minor bugs in the code and production
    - Metadata is receiving updates to make all the H-Series products self-describing and to meet CF standards
    - Ancillary products are also receiving minor updates for final production of ISCCP H-Series v01r00 product release.
    - A new website has also been developed and recently launched through NCEI to alert users of the H-Series products and the changes they can expect. The website can be accessed using the following link, http://www.ncdc.noaa.gov/isccp
- The ESA Cloud CCI project:

  Cloud_cci is producing two global long time series of the full suite of GCOS cloud parameters (plus additionally: cloud albedo and emissivity and per pixel uncertainty estimates) from two different optimal estimation retrieval approaches:

- ATSR2-AATSR-MODIS-AVHRR product covering 33 years, from 1982 to 2014.
- AATSR-MERIS synergy product covering 2002-2012. Although shorter, this second product makes novel use of the MERIS O2A band to provide a better characterisation of cloud-top height.

The development of these cloud products is led by CM-SAF leader DWD, and is embedded within the international GEWEX Cloud Assessment and EUMETSAT's Cloud Retrieval Evaluation Workshop (CREW) activities. Additional efforts to support users, such as integration of CCI cloud products in the CFMIP Observation Simulator Package (COSP) are in progress.

An FCDR consisting of intercalibrated AVHRR radiance data is also developed in collaboration with GSICS, SCOPE-CM and SST_cci.

See: http://www.esa-cloud-cci.org

References:

Bojanowski, J., R. Stöckli, A. Tetzlaff, and H. Kunz, 2014: The impact of time difference between satellite overpass and ground observation on cloud cover performance statistics. *Remote Sens*., **6**, 12866–12884, doi:10.3390/rs61212866.

Carbajal Henken, C. K., R. Lindstrot, R. Preusker, and J. Fischer, 2014: FAME-C: Cloud property retrieval using synergistic AATSR and MERIS observations. *Atmos*. *Meas*. *Tech*. *Disc*., **7**, 4909–4947, doi:10.5194/amtd-7-4909-2014.

Hollmann, R., and Coauthors, 2013: The ESA Climate Change Initiative: Satellite data records for essential climate variables. *Bull*. *Amer*. *Meteor*. *Soc*., **94**, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Hollstein, A., J. Fischer, C. Carbajal Henken, and R. Preusker, 2014: Bayesian cloud detection for MERIS, AATSR, and their combination. *Atmos*. *Meas*. *Tech*. *Disc*., **7**, 11045–11085, doi:10.5194/amtd-7-11045-2014.

Karlsson, K.-G., and E. Johansson, 2014: Multi-sensor calibration studies of AVHRR-heritage channel radiances using the simultaneous nadir observation approach. *Remote Sens*., **6**, 1845–1862, doi:10.3390/rs6031845.

Meirink, J. F., R. A. Roebeling, and P. Stammes, 2013: Inter-calibration of polar imager solar channels using SEVIRI. *Atmos*. *Meas*. *Tech*., **6**, 2495–2508, doi:10.5194/amt-6-2495-2013.

Stengel, M., and Coauthors, 2014: The Clouds Climate Change Initiative: The assessment of state of the art cloud property retrieval systems applied to AVHRR heritage measurements. *Remote Sens*. *Environ*..**162**, 363–379.

5.3.7.2 GCOS/CEOS Action A24; SS: A.6.1 to A.6.6 (cloud amount, cloud top pressure, cloud top temperature, cloud optical depth, cloud water path, and cloud effective particle radius)

Action: Research to improve observations of the three-dimensional spatial and temporal distribution of cloud properties.
Who: Parties' national research and space agencies, in cooperation with the WCRP.
Time-Frame: Continuous.
Performance Indicator: New cloud products.
Annual Cost Implications: 30-100M US$ (Mainly by Annex-I Parties).

CEOS Entities:

- **CEOS Agency Leads:** NASA
- **CEOS Agency Contributors:** NOAA, EUMETSAT, ESA, DLR
- **CEOS Coordination Mechanisms:** TBD

International Coordination Bodies: GDAP, International Radiation Commission (IRC)

Associated Organizations: TBD

Description of the Deliverable(s): A multi-year extra-polar cloud climate dataset that takes advantage of the recent and coming advances in the temporal and spatial capabilities of geostationary imagers (Geostationary Operational Environmental Satellite-R [GOES-R], Meteosat Third Generation [MTG]). The new cloud datasets will provide sub-hourly temporal variation of cloud properties with spatial resolutions less than 4km. The availability of additional spectral resolution will allow for products for multiple cloud layers. The current geostationary data will not provide continuous extra-polar coverage but this will be possible with the coming of GOES-R and other geostationary sensors that scan the full-disk with sub-hourly frequency.

Accuracy, stability, horizontal resolution, and vertical resolution

ECV: Cloud Properties	**GCOS/CEOS Action A24**			
		Property		
		Amount	Mass	Vertical Extent
Accuracy	Target	0.01-0.05	20%	1 km
	Planned	5%	10%	0.5
Stability (/decade)	Target	0.003-0.03	2%	2
	Planned	2%	2%	2
Horizontal resolution (km)	Target	5	4	4
	Planned	2	2	2
Vertical resolution	Target	2 layers	2 layers	2 layers
	Planned	1 km	1 km	1 km

Key activities and time frames to meet deliverables (2011 – 2015)

- Develop through GSICS the mechanism to calibrate all channels from the current and planned geostationary imagers.
- The research outlined here will be facilitated if geostationary data from all sensors where remapped to fixed projections as is done form Meteosat Second Generation (MSG)/Spinning Enhanced Visible and Infrared Imager (SEVIRI) and will be done for MTG and GOES-R. The use of a constant-projection will enable cloud object tracking between images and other complex temporal approaches.
- Lagrangian techniques for the study of cloud and aerosol interaction needed to be developed using methods that are applicable to large geostationary datasets.

2015 Update

Developments on the latest status of research on cloud parameter retrievals are presented and discussed at the Workshops of the CGMS International Clouds Working Group. A noticeable finding of the 4th Cloud Retrieval Evaluation Workshop (March 2014, Grainau, Germany) was the increased number of research groups that now implement optimal estimation methods in their operational retrievals. In addition, some research groups have started to combine observations from both passive and active instruments. While the active sensors provide information for only a very small portion of the imager swath, these observations are critical for improving global cloud parameter retrievals. Moreover, the preliminary results presented on the assessments of error estimates produced by some of the retrieval schemes were an important step towards quantifying these estimates in a more systematic manner. These assessments reveal that error estimates compare reasonably well in multiple algorithm ensembles or against the true uncertainty between retrieved and observed cloud parameters. Finally, the evaluation of aggregation methods and filtering rules revealed that the manner of aggregating or filtering level-2 data creates systematic differences in level-3 products that tend to vary regionally depending on climate regions and/or surface conditions. Although the differences are smaller than those between level-2 retrievals they are not negligible.

The main recommendations of the workshop towards future cloud retrieval research are:

- Improve cloud models used in retrievals to more accurately reflect reality, in particular ice crystal models, vertical in-homogeneity, and multiple layers;
- Explore the potential of combining different types of observations in level-2 cloud retrievals methods;
- Explore the definition of a set of essential filtering rules in level-3 aggregation methods for different cloud parameters;
- Work toward the characterisation of uncertainties in level-2 and level-3 products;
- Explore production of multi-algorithm ensembles to assess uncertainty/sensitivity;
- Explore the production of long-term datasets aimed at stability and accurate assessment of product strengths and weaknesses;

- Use common ancillary data and validation procedures for level-2 and level-3 data;
- Establish sub-working groups to make progress on a variety of outstanding issues, for example multi-layered clouds, severe weather applications, and aggregation methods.

5.3.8 Earth Radiation Budget

Importance of this ECV

The energy entering, reflected, absorbed, and emitted by the Earth system are the components of the Earth's radiation budget. Based on the physics principle of conservation of energy, this radiation budget represents the accounting of the balance between incoming radiation, which is almost entirely solar radiation, and outgoing radiation, which is partly reflected solar radiation and partly radiation emitted from the Earth system, including the atmosphere. A budget that's outof balance can cause the temperature of the atmosphere to increase or decrease and eventually affect our climate.

5.3.8.1 GCOS/CEOS Action A25; SS: A.7.2 (solar irradiance) and A.7.1 (Earth radiation budget)

Action: Ensure continuation of Earth Radiation Budget observations, with at least one dedicated satellite mission operating at any one time.
Who: Space agencies.
Time-Frame: Ongoing.
Performance Indicator: Long-term data availability at archives.
Annual Cost Implications: 30-100M US$ (Mainly by Annex-I Parties).

CEOS Entities:

- **CEOS Agency Leads:** NASA, NOAA
- **CEOS Agency Contributors:** EUMETSAT, ESA, CNES
- **CEOS Coordination Mechanisms:** WGCV

International Coordination Bodies: GDAP, Global Energy Balance Working Group of the IRC, CGMS, GSICS

Associated Organizations: IRC, ITT Geospatial Systems (IGS), University of Maryland, College Park (UMCP)

Specific Deliverable #1:

- Solar Irradiance

Specific Deliverable #2

- All-sky and Clear-sky Short Wave (SW), Long Wave (LW), and Net Top of the Atmosphere (TOA) Fluxes

Specific Deliverable #3

- All-sky and Clear-sky SW, LW, and Net SFC Fluxes

Accuracy, stability, horizontal resolution, and vertical resolution

For Deliverable #1:

ECV: Earth radiation budget	**GCOS/CEOS Action A25**		
	Property		
		Total solar irradiance	Spectral solar irradiance
Accuracy	Target	1 W/m^2	0.3 %
	Planned	1 W/m^2	0.3 %
Stability (/decade)	Target	0.3 W/m^2	0.1 %
	Planned	0.3 W/m^2	0.1 %

For Deliverable #2 (Planned values updated in 2015):

ECV: Earth radiation budget	**GCOS/CEOS Action A25**						
		Property					
		All-sky SW TOA Flux (Monthly)			All-Sky LW TOA flux (Monthly		
		Global	Zonal	Regional	Global	Zonal	Regional
Accuracy (Wm^{-2})	Target	1	1	1	1	1	1
	Planned	1	2	5	1	2	5
Stability ((Wm^{-2} /decade)	Target	0.3	0.3	0.3	0.3	0.3	0.3
	Planned	0.3	0.5	0.5	0.2	0.3	0.5
Horizontal resolution (km) (20-30 km footprint)	Target	N/A	TBD	100 km	TBD	TBD	TBD
	Planned	1° regional; 1° zonal; Global					

ECV: Earth radiation budget	**GCOS/CEOS Action A25**						
	Property						
		All-Sky Net TOA Flux (Monthly)			Clear-sky SW TOA Flux (Monthly)		
		Global	Zonal	Regional	Global	Zonal	Regional
Accuracy (Wm^{-2})	Target	TBD	TBD	TBD	TBD	TBD	TBD
	Planned	1.5	3	7	1	2	5
Stability ((Wm^{-2} /decade)	Target	TBD	TBD	TBD	TBD	TBD	TBD
	Planned	0.4	0.6	0.7	0.3	0.5	0.5
Horizontal resolution (20-30 km footprint)	Target	TBD	TBD	TBD	TBD	TBD	TBD
	Planned	1° regional; 1° zonal; Global					

ECV: Earth radiation budget	GCOS/CEOS Action A25						
	Property						
		Clear-sky LW TOA Flux (Monthly)			Clear-sky Net TOA Flux (Monthly		
		Global	Zonal	Regional	Global	Zonal	Regional
Accuracy (Wm^{-2})	Target	TBD	TBD	TBD	TBD	TBD	TBD
	Planned	1	2	5	1.5	3	7
Stability (Wm^{-2} /decade)	Target	TBD	TBD	TBD	TBD	TBD	TBD
	Planned	0.2	0.3	0.5	0.4	0.6	0.7
Horizontal resolution (20-30 km footprint)	Target	TBD	TBD	TBD	TBD	TBD	TBD
	Planned	1° regional; 1° zonal; Global					

For Deliverable #3 (Planned values updated in 2015):

ECV: Earth radiation budget	GCOS/CEOS Action A25						
	Property						
		Surface radiation budget (Monthly 3-hr,regional mean)					
		All-sky SW SFC Flux	All-Sky LW SFC flux	All-Sky Net SFC Flux	Clear-sky SW SFC Flux	Clear-sky LW SFC Flux	Clear-sky Net SFC Flux
Accuracy (Wm^{-2})	Target	1	1	TBD	TBD	TBD	TBD
	Planned	10	10	15	10	10	15
Stability (Wm^{-2} /decade)	Target	0.3	0.3	TBD	TBD	TBD	TBD
	Planned	0.3	0.3	0.4	0.3	0.3	0.4
Horizontal resolution (20-30 km footprint)	Target	100 km	100 km	TBD	TBD	TBD	TBD
	Planned	1° regional; 1° zonal; Global					

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

- CERES FM1-4 are currently flying aboard Terra and Aqua
- CERES FM5 is currently flying on NPP.
- Geostationary Earth Radiation Budget (GERB) is currently flying on Meteosat-8, -9, -10, and -11.
- Scanner for Radiation Budget (ScaRaB) is currently flying on Megha-Tropiques.
- Broadband Radiometer (BBR) is scheduled to fly on EarthCARE in 2014.

2015 Update

The Total Solar Irradiance Calibration Transfer Experiment (TCTE) measures total solar irradiance (TSI), or the total light coming from the Sun at all wavelengths, in order to monitor changes in the incident sunlight at the top of Earth's atmosphere. The mission mitigates a potential and likely upcoming gap in an otherwise continuous 34-year climate data record following the loss of the NASA Glory mission in 2011. TCTE was successfully launched on November 19, 2013.

Planned: ISS/TSIS with launch in 2017 and continued follow-on missions (from TSIS Performance Requirements)

TSI accuracy 0.01% (0.14 W/m^2) and stability 0.01%/decade (0.14 W/m^2/decade)

SSI accuracy 0.2% and Stability 0.5%/decade for wavelengths <400 nm and 0.1%/decade at wavelengths >400nm

Solar irradiance:

In the frame of CEOS WGCV the solar irradiance spectrum is under reevaluation since 2014 in cooperation between the CEOS WGCv subgroups for Atmospheric Composition (ACSG) and Infrared and Visible Optical Sensors (IVOS). The activity aims to identify the most suitable solar irradiance spectrum in terms of retrieval, calibration, and validation.

Activity updates on solar irradiance measurements:

- ESA's SoHO/VIRGO (TSI) functioning since 1996
- NASA's ACRIMSat/ACRIM3 (TSI) ceased operations in Nov. 2013
- NASA's SORCE/TIM (TSI) continuing since 2003 and achieving target requirements above
- NASA's SORCE/SIM (SSI) continuing since 2003 but not achieving target requirements above
- CNES Picard/PREMOS (TSI) 2010-2014 achieved accuracy target requirements above
- NOAA's STP-Sat3/TCTE/TIM (TSI) launched Nov. 2013 and achieving target requirements above
- NORSAT1/CLARA (TSI) planned for 2016 launch
- NOAA's ISS/TSIS (TSI & SSI) planned for 2017 launch to achieve target and exceed planned requirements given in table above

Earth radiation budget:

CERES FM6 will fly on JPSS-1 in the 2016 timeframe

Broadband Radiometer (BBR) is scheduled to fly on EarthCARE in late 2015.

Responsibility for continuity of Earth radiation observations in the United States has been transferred back to NASA from NOAA. NASA is currently developing the next generation Radiation Budget Instrument (RBI) and it will fly on JPSS-2 in the 2021 timeframe.

References:

Doelling, D. R., N. G. Loeb, D. F. Keyes, M. L. Nordeen, D. Morstad, C. Nguyen, and M. Sun, 2013: Geostationary enhanced temporal interpolation for CERES flux products. *J. Atmos. Oceanic Tech.*, **30**, 1072–1090. doi:10.1175/JTECH-D-12-00136.1

Kato, S., N. G. Loeb, F. G. Rose, D. R. Doelling, D. A. Rutan, T. E. Caldwell, L. Yu, and R. Weller, 2013: Surface irradiances consistent with CERES-derived top-of-atmosphere shortwave and longwave irradiances. *J. Climate*, **26**, 2719–2740, doi:10.1175/JCLI-D-12-00436.1.

Kato, S., N. G. Loeb, D. A. Rutan, F. G. Rose, S. Sun-Mack, W. F. Miller, and Y. Chen, 2012: Uncertainty estimate of surface irradiances computed with MODIS-, CALIPSO-, and CloudSat-derived cloud and aerosol properties. *Surveys Geophys.*, **33**, 395–412, doi:10.1007/s10712-012-9179-x.

Loeb, N. G., D. A. Rutan, S. Kato, and W. Wang, 2014: Observing interannual variations in Hadley circulation atmospheric diabatic heating and circulation strength. *J. Climate*, **27**, 4139–4158, doi:10.1175/JCLI-D-13-00656.1

Loeb, N. G., S. Kato, W. Y. Su, T. M. Wong, F. G. Rose, D. R. Doelling, J. R. Norris, and X. L. Huang, 2012: Advances in understanding top-of-atmosphere radiation variability from satellite observations. *Surveys Geophys*, **33**, 359–385, doi:10.1007/s10712-012-9175-1.

Rutan, D. A., S. Kato, D. R. Doelling, F. G. Rose, C. Nguyen, T. Caldwell, and N. G. Loeb, 2014: CERES Synoptic product: Methodology and validation of surface radiant flux. *J. Atmos. Oceanic Tech.*, in press, doi:10.1175/JTECH-D-14-00165.1

5.3.9 Atmospheric Composition

Importance of this ECV

This ECV focuses on the chemistry of the stratosphere; the Climate Action associated with it concentrates on limb scanning observations.

Although a minor gas, ozone, mainly concentrated in a layer in the stratosphere, is vital for life on Earth: it shields humans, flora, and fauna from the harmful ultraviolet light from the Sun. Intense UV radiation in the upper atmosphere produces ozone (O_3).The radiation breaks typical oxygen molecules (O_2) into free oxygen atoms (O). A free oxygen atom (O) can then join with an oxygen molecule (O_2) to form a molecule of ozone (O3). Chemical reactions involving gases such as chlorine, bromine, nitrogen, and hydrogen destroy ozone. The ozone depletion over Antarctica results from the combined actions of very cold conditions, the return of sunlight in the Antarctic spring, and ozone depleting chemicals, which mostly come from human-produced compounds, in particular chlorofluorocarbons (CFCs). As a result of the phasing-out of the harmful CFCs, the ozone layer is now recovering and continuing observations are needed to monitor this recovery.

In the stratosphere, water vapor is a source gas for OH which is chemically active in the ozone budget. Changes in stratospheric water vapor also influence the greenhouse effect.

5.3.9.1 GCOS/CEOS Action A26; SS: A.9.3 (ozone), A.5.2 (water vapour), A.8.1 (CO_2 and CH_4)

Action: Establish long-term limb-scanning satellite measurement of profiles of water vapour, ozone and other important species from the UT/LS up to 50 km.
Who: Space agencies, in conjunction with WMO GAW.
Time-Frame: Ongoing, with urgency in initial planning to minimize data gap.
Performance Indicator: Continuity of UT/LS and upper stratospheric data records.
Annual Cost Implications: 100–300M US$ (including mission costs) (Mainly by Annex-I Parties).

CEOS Entities:

- **CEOS Agency Leads:** CSA, ESA, NASA, NOAA
- **CEOS Agency Contributors**: JAXA/NIES/NICT
- **CEOS Coordination Mechanisms**: Atmospheric Composition VC

International Coordination Bodies: TBD

Associated Organizations: TBD

Specific Deliverable #1:

- Assess past limb sounding ozone and other trace gas measurements, together with near-term planned space-based missions to determine their suitability for use in fused data sets. The data generated need to be available to users in a user-aimed fashion.

Relevant species measured using limb sounding methods.

Species	Wavelength Range
O_3	UV/VIS/IR/MW
H_2O	NIR/TIR
N_2O	(TBD)
NO	(TBD)
BrO	UV
NO_2	UV
ClO (LS)	MW and TIR
OClO (LS)	UV
PSCs	UV/Vis + TIR
Aerosols	UV/Vis
(H)CFCs	TIR
ClO	(TBD)
HCl	TIR
HOCl	MW
OH/HO_2	MW
$ClONO_2$	TIR
HNO_3	TIR

Accuracy, stability, horizontal resolution, and vertical resolution

ECV: Water vapor, ozone, and other important species	**GCOS/CEOS Action A26**								
		Property							
		O_3		**H_2O**		**CH_4**		**NO_x-species**	
		5-25 km	25-50 km	5-25 km	25-50 km	5-25 km	25-50 km	5-25 km	25-50 km
Accuracy (%)	Target	10	5-20	5	TBD	10 ppb	5	TBD	TBD
	Planned	5	3	5	5	8	5	10	5
Stability (%/7yr)	Target	1	1	0.3	TBD	2 ppb	0.3	TBD	TBD
	Planned	1	1	TBD	TBD	TBD	TBD	TBD	TBD
Horizontal resolution (km)	Target	100-200	100-200	25	TBD	5-10	100-200	TBD	TBD
	Planned	100	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Vertical resolution (km)	Target	1-2	3	TBD	TBD	5	2	TBD	TBD
	Planned	0.5	2	TBD	TBD	TBD	TBD	TBD	TBD

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

- Launch SAGE III-ISS and Sentinel 5-Precursor as currently planned.
- Agencies need to create plans and allocate funding for additional limb sensors to fly from 2015 to 2025. See, e.g., National Research Council (NRC) Decadal Survey (http://www.nap.edu/catalog.php?record_id=11820).
- Development of climate data records (CDRs) for U.S. sensors needs to be merged with efforts using records from other sensors, *e.g*., Optical Spectrograph and Infrared Imaging System [OSIRIS], Global Ozone Monitoring by Occultations of Stars [GOMOS], Scanning Imaging Absorption SpectroMeter for Atmospheric CartograpHY [SCIAMACHY]. These records are of sufficient length to begin this work (see, also, issues in next section with respect to agency resources).
- Work is needed to determine how well UV/Vis Limb Scatter can continue occultation ozone and aerosol records. This activity will progress during the recently-launched Suomi NPP mission and the forthcoming SAGE III-ISS mission.

2015 Update

The Canadian Space Agency approved the continuation of the SCISAT mission through the end of 2015. The atmospheric chemistry experiment (ACE) Fourier transform infrared spectrometer is unique in its ability to make measurements of upper atmosphere chemistry in the trace gases responsible for ozone depletion. A complete review of this experiment can be found at the following website http://www.ace.uwaterloo.ca/index.html

Limb Sounding Mission Gap

Participants in the CEOS Atmospheric Chemistry Virtual Constellation meeting of 2014 recognize the significance of the looming gap in limb sounding data. Following the demise of the currently operating but aging instruments:

- MLS on Aura (microwave emission),
- SMR (microwave emission) on Odin,
- OSIRIS (limb scatter UV-Vis-NIR) on Odin,
- ACE-FTS (solar occultation IR) on SCISAT, and
- ACE-MAESTRO (solar occultation UV-Vis-NIR) on SCISAT,

the only limb sounding instruments will be:

- OMPS Limb Profiler on Suomi-NPP (limb scatter UV-Vis-NIR),
- SAGE-III/ISS (solar occultation & limb scatter UV-Vis-NIR, planned for 2016),
- OMPS Limb Profiler on JPSS-2 (limb scatter UV-Vis-NIR, planned for ~2021).

Specific Deliverable #2

Maximize use of existing sensors and develop a collaborative framework to advocate and facilitate near-term calibration/validation activities and other coordinated science team planning for near-term space-based missions with limb sounding capability (e.g., to include, but not limited to, Stratospheric Aerosol and Gas Experiment (SAGE) III-ISS and Sentinel 5-Precursor) to maximize scientific output.

5.3.9.2 GCOS/CEOS Action A27; A.11.1

Action: Establish a network of ground stations (MAXDOAS, lidar, FTIR) capable of validating satellite remote sensing of the troposphere.
Who: Space agencies, working with existing networks and environmental protection agencies.
Time-Frame: Urgent.
Performance Indicator: Availability of comprehensive validation reports and near real-time monitoring based on the data from the network.
Annual Cost Implications: 10-30M US$ (30% in non-Annex-I Parties).

ESA's European Space Research Institute (ESRIN) has been supporting since 2008 the instrumental intercalibration and algorithm evolution of Dobson/Brewer, Differential Optical Absorption Spectroscopy (DOAS) and EarliNet lidar systems for the purpose of having access to fully characterized ground based dataset for the validation of satellite-derived atmospheric composition measurements. This activity will be extended by ESA to address upcoming satellite air quality needs by establishing a dedicated calibrated ground based measurement network of spectrometers, as well as focus on the improvement of DOAS-based profile retrievals of trace gases *(i.e.,* MaxDOAS).

2015 Update

ESA is extending its R&D activities for DOAS and Max-DOAS in cooperation with NDACC and CEOS WGCV subgroup Atmospheric Composition. Updated information on in situ networks can be found at the global atmospheric watch website: http://www.wmo.int/pages/prog/arep/gaw/gaw_home_en.html.

5.3.10 Carbon Dioxide and Methane, and other GHGs

Importance of this ECV

Carbon dioxide, injected into the atmosphere by the burning of fossil fuels, is the major anthropogenic greenhouse gas. Methane, the second most important anthropogenic greenhouse gas, is introduced into the atmosphere by using natural gas, animal husbandry (enteric fermentation in livestock and manure management), rice cultivation, biomass burning, and waste management. Understanding the sources and sinks for CO_2 and CH_4 is crucial. One of the challenges is to distinguish between natural and anthropogenic sources, for which accurate global measurements are required.

5.3.10.1 GCOS/CEOS Action A28; SS A.8.1

Action: Maintain and enhance the WMO GAW Global Atmospheric CO2 and CH4 Monitoring Networks as major contributions to the GCOS Comprehensive Networks for CO2 and CH4.
Who: Parties' national services, research agencies, and space agencies, under the guidance of WMO GAW and its Scientific Advisory Group for Greenhouse Gases, in cooperation with the AOPC.
Time-Frame: Ongoing.
Performance Indicator: Dataflow to archive and analyses centres.
Annual Cost Implications: 10-30M US$ (50% in non-Annex-I Parties).

The complete CEOS response to this action is under development.

2015 Update

ESA, in cooperation with CEOS WGCV subgroup Atmospheric Composition, NDACC, and TCOON, will support a 2-year field intercomparison of the different type of FTIR instruments used for GHG satellite validation. In addition, an aircraft-based measurement system for GHG is set up in cooperation with University of Bremen. Updated information on in situ networks can be found at the global atmospheric watch website: http://www.wmo.int/pages/prog/arep/gaw/gaw_home_en.html

5.3.10.2 GCOS/CEOS Action A29; SS A.8.1

Action: Assess the value of the data provided by current space-based measurements of CO2 and CH4, and develop and implement proposals for follow-on missions accordingly.
Who: Parties' research institutions and space agencies.
Time-Frame: Urgent, to minimise data gap following GOSAT.
Performance Indicator: Assessment and proposal documents; approval of consequent missions.
Annual Cost Implications: 1-10M US$ initially, increasing with implementation (10% in non-Annex-I Parties).

CEOS Entities:

- **CEOS Agency Leads:** CSA, ESA, NASA, NOAA
- **CEOS Agency Contributors**: JAXA, CNES
- **CEOS Coordination Mechanisms**: SIT (replacing the ad hoc CEOS Carbon Task Force for the coordination of all carbon-related tasks.)

International Coordination Bodies: GEO

Associated Organizations: ESA Climate Change Initiative CCI (esa.cci.int)

Specific Deliverable(s):

- Several releases of validated time-series of SCIAMACHY, Greenhouse gases Observing Satellite (GOSAT/IBUKI), and Orbiting Carbon Observatory-2 (OCO-2) (after launch in 2014) CH_4 and CO_2 Level 2 and Level 3 data over instrument lifetimes with clear error characterization.
- These data should enable the derivation of regional sources and sinks of greenhouse gases.

Accuracy Requirements:

Requirements for regional CO_2 and CH_4 source/sink determination using SCIAMACHY/ENVISAT and TANSO/GOSAT/IBUKI					
Parameter	**Req. type**	**Random error** ("Precision")		**Systematic error** ("Accuracy")	**Stability**
		Single obs.	1000^2 km^2 monthly		
XCO_2	G	< 1 ppm	< 0.3 ppm	< 0.2 ppm (absolute)	As systematic error but per year
	B	< 3 ppm	< 1.0 ppm	< 0.3 ppm (relative §))	As systematic error but per year
	T	< 8 ppm	< 1.3 ppm	< 0.5 ppm (relative #))	As systematic error but per year
XCH_4	G	< 9 ppb	< 3 ppb	< 1 ppb (absolute)	As systematic error but per year
	B	< 17 ppb	< 5 ppb	< 5 ppb (relative §))	As systematic error but per year
	T	< 34 ppb	< 11 ppb	< 10 ppb (relative #))	As systematic error but per year

Abbreviations: G=Goal, B=Breakthrough, T=Threshold requirement.
§) Required systematic error after bias correction, where only the application of a constant offset / scaling factor independent of time and location is permitted for bias correction.
#) Required systematic error after bias correction, where bias correction is not limited to the application of a constant offset / scaling factor.

XCO_2 and XCH_4 random ("precision") and systematic ("accuracy") retrieval error requirements for measurements over land.

Threshold requirement: The **threshold** is the minimum requirement to be met to ensure that data are useful.

Goal requirement: The **goal** is an ideal requirement above which further improvements are not necessary.

Breakthrough requirement: The **breakthrough** is an intermediate level between "threshold" and "goal", which, if achieved, would result in a significant improvement for the targeted application. The breakthrough level may be considered as an optimum, from a cost-benefit point of view when planning or designing observing systems.

Key activities and time frames to meet deliverables (2011 – 2015)

- Parallel algorithm improvement and application to SCIAMACHY and GOSAT/IBUKI Level 1 data
- Algorithms/Level 2 data intercomparison
- Algorithms selection for dataset generation
- Algorithms geophysical validation
- Greenhouse gas (GHG) dataset evaluation by models
- Data Reprocessing
- Documentation (algorithm, error characterization, product format)
- The ESA Climate Change Initiative initiated a GHG CCI Project covering CO_2 and CH_4 with the objective t improve retrieval accuracies and coverage.

2015 Update

CEOS, as the primary international forum for coordination of space-based Earth observations, recently published a response to the Group on Earth Observation's (GEO's) Carbon Observation Strategy: the CEOS Strategy for Carbon Observations from Space. The CEOS Strategy details the adequacy of past, present, and planned satellite measurements of carbon in the land, oceans and inland waters, and atmosphere domains to support GEO. Specifically, it identifies important actions CEOS and its Agencies must take to better coordinate existing and future capabilities, as well as challenges that require additional resources and/or mandates beyond the present capacity of CEOS and its member Agencies. The report can be found here: http://ceos.org/document_management/Publications/WGClimate_CEOS-Strategy-for-Carbon-Observations-from-Space_Apr2014.pdf. Because the CEOS Carbon Task Force had been installed as an ad hoc team, the resulting tasks from the action items of the report are now coordinated by the CEOS SIT team. The Carbon Task Force has been closed with fulfillment of its work plan.

- GHG_cci has developed and tested multiple algorithms to improve CO_2 and CH_4 retrieval accuracies and coverage
  - Core products: Column average CO2 and CH4 from SCIAMACHY (2002-2012) and TANSO (2009-2014).
  - Extra column and profile products providing additional modelling constraints, but which have reduced sensitivity to boundary layer CO2 and CH4 concentration are provided from MIPAS, SCIAMACHY, AIRS, ACE-FTS, and IASI.

  Additionally, multi-mission ensemble products have been prototyped for CO_2. Trials of prototype retrievals for new instruments will be included as part of the project depending on launch dates: OCO-2, TanSat, Sentinel-5P, Merlin, GOSAT-2.

  All developments are taking place in close collaboration with the NASA-ACOS team and the GOSAT teams at NIES and JAXA.

  See: http://www.esa-ghg-cci.org

References:

Alexe, M., and Coauthors, 2015: Inverse modelling of CH4 emissions for 2010–2011 using different satellite retrieval products from GOSAT and SCIAMACHY. *Atmos. Chem. Phys.*, **15**, 113–133, doi:10.5194/acp-15-113-2015.

Basu, S., and Coauthors, 2013: Global CO2 fluxes estimated from GOSAT retrievals of total column CO2. *Atmos. Chem. Phys.*, **13**, 8695–8717, doi:10.5194/acp-13-8695-2013.

Basu, S., and Coauthors, 2014: The seasonal variation of the CO 2 flux over Tropical Asia estimated from GOSAT, CONTRAIL, and IASI. *Geophys. Res. Lett.*, **41**, 1809–1815, doi:10.1002/2013GL059105.

Buchwitz, M., and Coauthors, 2013: Carbon Monitoring Satellite (CarbonSat): assessment of scattering related atmospheric CO2 and CH4 retrieval errors and first results on implications for inferring city CO2 emissions. *Atmos. Meas. Tech. Disc.*, **6**, 4769–4850, doi:10.5194/amtd-6-4769-2013.

Buchwitz, M., and Coauthors, 2013: The Greenhouse Gas Climate Change Initiative (GHG-CCI): Comparison and quality assessment of near-surface-sensitive satellite-derived CO2 and CH4 global data sets. *Remote Sens. Environ.*. 162, 344–362, doi:10.1016/j.rse.2013.04.024.

Butz, A., and Coauthors, 2011: Toward accurate CO 2 and CH 4 observations from GOSAT. *Geophys. Res. Lett.*, **38**, L14812, doi:10.1029/2011GL047888.

Chevallier, F., and C. W. O'Dell, 2013: Error statistics of Bayesian CO 2 flux inversion schemes as seen from GOSAT. *Geophys. Res. Lett.*, **40**, 1252–1256, doi:10.1002/grl.50228.

Chevallier, F., P. I. Palmer, L. Feng, H. Boesch, C. W. O'Dell, and P. Bousquet, 2014: Toward robust and consistent regional CO 2 flux estimates from in situ and spaceborne measurements of atmospheric CO 2. *Geophys. Res. Lett.*, **41**, 1065–1070, doi:10.1002/2013GL058772.

Cressot, C., and Coauthors, 2013: On the consistency between global and regional methane emissions inferred from SCIAMACHY, TANSO-FTS, IASI and surface measurements. *Atmos. Chem. Phys. Disc.*, **13**, 8023–8064, doi:10.5194/acpd-13-8023-2013.

Crevoisier, C., and Coauthors, 2013: The 2007–2011 evolution of tropical methane in the mid-troposphere as seen from space by MetOp-A/IASI. *Atmos. Chem. Phys.*, **13**, 4279–4289, doi:10.5194/acp-13-4279-2013.

Dils, B., and Coauthors, 2013: The Greenhouse Gas Climate Change Initiative (GHG-CCI): Comparative validation of GHG-CCI SCIAMACHY/ENVISAT and TANSO-FTS/GOSAT CO2 and CH4 retrieval algorithm products with measurements from the TCCON network. *Atmos. Meas. Tech. Disc.*, **6**, 8679–8741, doi:10.5194/amtd-6-8679-2013.

Fraser, A., and Coauthors, 2012: Estimating regional methane surface fluxes: The relative importance of surface and GOSAT mole fraction measurements. *Atmos. Chem. Phys. Disc.*, **12**, 30989–31030, doi:10.5194/acpd-12-30989-2012.

Fraser, A., and Coauthors, 2014: Estimating regional fluxes of CO2 and CH4 using space-borne observations of XCH4 : XCO2. *Atmos. Chem. Phys. Disc.*, **14**, 15867–15894, doi:10.5194/acpd-14-15867-2014.

Guerlet, S., and Coauthors, 2013: Reduced carbon uptake during the 2010 Northern Hemisphere summer from GOSAT. *Geophys. Res. Lett.*, **40**, 2378–2383, doi:10.1002/grl.50402.

Guerlet, S., and Coauthors, 2013: Impact of aerosol and thin cirrus on retrieving and validating XCO 2 from GOSAT shortwave infrared measurements. *J. Geophys. Res. Atmos.*, **118**, 4887–4905, doi:10.1002/jgrd.50332.

Heymann, J., and Coauthors, 2012: SCIAMACHY WFM-DOAS XCO2: Reduction of scattering related errors. *Atmos. Meas. Tech.*, **5**, 2375–2390, doi:10.5194/amt-5-2375-2012.

Heymann, J., and Coauthors, 2012: SCIAMACHY WFM-DOAS XCO2: Comparison with CarbonTracker XCO2 focusing on aerosols and thin clouds. *Atmos. Meas. Tech.*, **5**, 1935–1952, doi:10.5194/amt-5-1935-2012.

Hollmann, R., and Coauthors, 2013: The ESA Climate Change Initiative: Satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, **94**, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Monteil, G., and Coauthors, 2013: Comparison of CH 4 inversions based on 15 months of GOSAT and SCIAMACHY observations. *J. Geophys. Res. Atmos.*, **118**, 11,807–11,823, doi:10.1002/2013JD019760.

Noël, S., K. Bramstedt, A. Rozanov, H. Bovensmann, and J. P. Burrows, 2011: Stratospheric methane profiles from SCIAMACHY solar occultation measurements derived with onion peeling DOAS. *Atmos. Meas. Tech.*, **4**, 2567–2577, doi:10.5194/amt-4-2567-2011.

Parker, R., and Coauthors, 2011: Methane observations from the Greenhouse Gases Observing SATellite: Comparison to ground-based TCCON data and model calculations. *Geophys. Res. Lett.*, **38**, L15807, doi:10.1029/2011GL047871.

Reuter, M., and Coauthors, 2013: A joint effort to deliver satellite retrieved atmospheric CO2 concentrations for surface flux inversions: the ensemble median algorithm EMMA. *Atmos. Chem. Phys.*, **13**, 1771–1780, doi:10.5194/acp-13-1771-2013.

Reuter, M., and Coauthors, 2011: Retrieval of atmospheric CO 2 with enhanced accuracy and precision from SCIAMACHY: Validation with FTS measurements and comparison with model results. *J. Geophys. Res. Atmos.*, **116**, D04301, doi:10.1029/2010JD015047.

Reuter, M., and Coauthors, 2012: On the potential of the 2041–2047nm spectral region for remote sensing of atmospheric CO2 isotopologues. *J. Quant. Spectrosc. Rad. Trans.*, **113**, 2009–2017, doi:10.1016/j.jqsrt.2012.07.013.

Reuter, M., Buchwitz, M., Hilboll, A., Richter, A., Schneising, O., Hilker, M., … Burrows, J. P. (2014). Decreasing emissions of NOx relative to CO2 in East Asia inferred from satellite observations. *Nature Geoscience*, advance on(11), 792–795. doi:10.1038/ngeo2257

Reuter, M., and Coauthors, 2014: Satellite-inferred European carbon sink larger than expected. *Atmos. Chem. Phys.*, **14**, 13739–13753, doi:10.5194/acp-14-13739-2014.

Reuter, M., and Coauthors, 2012: A simple empirical model estimating atmospheric CO2 background concentrations. *Atmos. Meas. Tech.*, **5**, 1349–1357, doi:10.5194/amt-5-1349-2012.

Ross, A. N., M. J. Wooster, H. Boesch, and R. Parker, 2013: First satellite measurements of carbon dioxide and methane emission ratios in wildfire plumes. *Geophys. Res. Lett.*, **40**, 4098–4102, doi:10.1002/grl.50733.

Schepers, D., and Coauthors, 2012: Methane retrievals from Greenhouse Gases Observing Satellite (GOSAT) shortwave infrared measurements: Performance comparison of proxy and physics retrieval algorithms. *J. Geophys. Res. Atmos.*, **117**, D10307, doi:10.1029/2012JD017549.

Schneising, O., M. Buchwitz, M. Reuter, J. Heymann, H. Bovensmann, and J. P. Burrows, 2011: Long-term analysis of carbon dioxide and methane column-averaged mole fractions retrieved from SCIAMACHY. *Atmos. Chem. Phys.*, **11**, 2863–2880, doi:10.5194/acp-11-2863-2011.

Schneising, O., J. P. Burrows, R. R. Dickerson, M. Buchwitz, M. Reuter, and H. Bovensmann, 2014: Remote sensing of fugitive methane emissions from oil and gas production in North American tight geologic formations. *Earth's Future*, **2**, 548–558, doi:10.1002/2014EF000265.

Schneising, O., J. Heymann, M. Buchwitz, M. Reuter, H. Bovensmann, and J. P. Burrows, 2013: Anthropogenic carbon dioxide source areas observed from space: Assessment of regional enhancements and trends. *Atmos. Chem. Phys.*, **13**, 2445–2454, doi:10.5194/acp-13-2445-2013.

Schneising, O., M. Reuter, M. Buchwitz, J. Heymann, H. Bovensmann, and J. P. Burrows, 2013: Terrestrial carbon sink observed from space: Variation of growth rates and seasonal cycle amplitudes in response to interannual surface temperature variability. *Atmos. Chem. Phys. Disc.*, **13**, 22733–22755, doi:10.5194/acpd-13-22733-2013.

Sussmann, R., F. Forster, M. Rettinger, and P. Bousquet, 2012: Renewed methane increase for five years (2007–2011) observed by solar FTIR spectrometry. *Atmos. Chem. Phys.*, **12**, 4885–4891, doi:10.5194/acp-12-4885-2012.

Sussmann, R., and Coauthors, 2013: First intercalibration of column-averaged methane from the Total Carbon Column Observing Network and the Network for the Detection of Atmospheric Composition Change. *Atmos. Meas. Tech.*, **6**, 397–418, doi:10.5194/amt-6-397-2013.

Wecht, K. J., and Coauthors, 2014: Spatially resolving methane emissions in California: Constraints from the CalNex aircraft campaign and from present (GOSAT, TES) and future (TROPOMI, geostationary) satellite observations. *Atmos. Chem. Phys. Disc.*, **14**, 4119–4148, doi:10.5194/acpd-14-4119-2014.

5.3.11 Ozone

Importance of this ECV

The importance of stratospheric ozone is discussed in Section 5.3.9. In the troposphere, high levels of ozone act as a pollutant as well as a greenhouse gas. Increasing tropospheric ozone concentrations result from photochemical processes involving nitrogen dioxides injected into the atmosphere by industrial emissions and automobile exhausts.

5.3.11.1 GCOS/CEOS Action 32; SS: A.9.1 (total column ozone), A..9.2 (tropospheric ozone), and A.9.3 (ozone profiles)

Action: Continue production of satellite ozone data records (column, tropospheric ozone and ozone profiles) suitable for studies of interannual variability and trend analysis. Reconcile residual differences between ozone datasets produced by different satellite systems.
Who: Space agencies.
Time-Frame: Ongoing.
Performance Indicator: Statistics on availability and quality of data.
Annual Cost Implications: 10-30M US$ (Mainly by Annex-I Parties).

CEOS Entities:

- **CEOS Agency Leads:** TBD
- **CEOS Agency Contributors**: ESA, EUMETSAT, NASA, NOAA, CSA, CNES, DLR
- **CEOS Coordination Mechanisms**: Atmospheric Composition Virtual Constellation

International Coordination Bodies: International Ozone Commission (IO3C), WCRP Stratospheric Processes and their Role in Climate (SPARC), WMO

Associated Organizations: ESA Climate Change Initiative CCI (esa.cci.int)

Specific Deliverable(s): Series of Instrument Specific Ozone Data Sets (total columns, profiles) with clear error characterization.

Accuracy, stability, horizontal resolution, and vertical resolution

ECV: Ozone	GCOS/CEOS Action A32			
		Property (Total O_3)		
		Tropics	Mid-latitudes	Polar Regions
Accuracy	Target	max(2%; 5DU)	max(2%; 5DU)	max(2%; 5DU)
	Planned	2% (7 DU)	2% (7 DU)	2% (7 DU)
Stability (%/decade)	Target	1	1	1
	Planned	3	3	3
Horizontal resolution (km)	Target	20-50	20-50	20-50
	Planned	100	50-100	50-100
Vertical resolution	N/A			

ECV: Ozone	GCOS/CEOS Action A32			
		Property (nadir based profiles)		
		Profile O_3, Troposphere	Profile O_3, UT/LS	Profile O_3, Middle atmosphere
Accuracy (%)	Target	10-15	10	
	Planned	10	8	8
Stability (%/decade)	Target	1	1	1
	Planned	3	3	3
Horizontal resolution (km)	Target	20-50	100-200	20
	Planned	200	50-100	50-100
Vertical resolution (km)	Target	5	3	3
	Planned	Tropospheric column	6	10

ECV: Ozone	GCOS/CEOS Action A32		
	Property (limb-based profiles)		
		Profile O_3, Lower stratosphere	Profile O_3, Middle stratosphere
Accuracy (%)	Target	10	5-20
	Planned	8	8
Stability (%/decade)	Target	1	1
	Planned	3	3
Horizontal resolution (km)	Target	100-200	100-200
	Planned	300	300
Vertical resolution (km)	Target	1-2	3
	Planned	3	5

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

For Deliverables 1 and 2

- Suomi NPP launch (Ozone Mapping and Profiler Suite [OMPS]) – October 2011
- EOS-AURA operations as long as instruments are functional (up to 2020)
- Decomissioning of ERS-2 in 2011
- Envisat operations to 2012 (mission terminated in 2012)
- Metop-A operations to at least 2012
- GOSAT/IBUKI operations to at least 2014
- Odin operations (with ESA support) to at least 2012
- Atmospheric Chemistry Experiment-Fourier Transform Spectrometer (ACE-FTS) operations to at least 2012
- Metop-B launch – September 2012
- Launch of new satellites – *e.g.*, Sentinel 5 precursor 2014, SAGE III-ISS 2014
- The ESA Climate Change Initiative initiated a Ozone CCI Project to produce a long time series of total column and ozone vertical profile measurements.

2015 Update

1. Total Ozone
1.a. NOAA Instruments on Polar Orbiters at 13:30.

The last remaining SBUV/2 on NOAA-19 POES is working well but its orbit has drifted past 2:00 PM Equator- crossing time and is headed even later. It has had some minor problems with one of the reflectivity channles but is continuing the long-term SBUV/2 total ozone record.

The OMPS Nadir Mapper on S-NPP is working very well. It is a stable instrument and on-board monitoring is providing calibration characterization that is expected to meet its stability requirement of 1% over the lifetime of the mission. We have added procedures to make stray light and wavelength scale correction using both on- ground characterization and in-orbit consistency checks to generate accurate level 1 products with high signal to noise ratios. Comparisons of reprocessed data sets for the first three years (provide by the NASA Ozone PEATE) show a total ozone record that that meets the 2% accuracy target. Its horizontal resolution is currently 50 KM at nadir and increases with viewing angle. We expect to implement the V8 Total Ozone algorithm in operations (in place of the current algorithm) and make soft calibration adjustments to the Level 1 product at the same time to produce a close to CDR quality operational product within the next year. (Aside: The adaptation of the V8 total ozone algorithm for use with OMPS was supported by an NCDC project.)

The next OMPS Nadir Mapper will be launched on JPSS-1 in 2017. It has passed its pre-shipment review. We expect to increase the horizontal resolution by a factor of three (to ~17 KM at nadir) but maintain the accuracy and stability of the products. This will be followed by a third and final OMPS on JPSS-2.

1.b. Instruments at L-1 and GEO.

The DSCOVR mission (joint NOAA/NASA) will be place at the Lagrange-1 Point and have the EPIC instrument on-board. This ten-channel filter CCD array instrument will make measurements of total ozone over the sunlit face of the Earth. It is scheduled for launch early next year (2015). We plan to use it as a transfer standard for total ozone measurements from low-Earth-orbiting sensors. (I have attached a poster on EPIC and the three instruments in the next section as well as some plans for their use for comparisons and inter-calibration.)

1.c. Instruments on Geostationary platforms

In the 2018-2020 time frame there are plans for at least three hyperspectral atmospheric composition instruments - NASA TEMPO, Korea's GEMS, and ESA's UVN. These instruments will produce good ozone measurements with high spatial and temporal resolution over their targeted areas - North America, Asia, and Europe, respectively. Again comparisons with other satellite measurements will help to provide a stable system of ozone monitoring instruments.

1.d. ESA Instruments on Polar orbiter and NASA OMI.

Ozone_cci has produced long time series of total column from multiple nadir and limb sounding instruments. Per retrieval uncertainty estimates are provided in the products.
16 years (1996-2014) of harmonised total column O_3 records from GOME, SCIAMACHY, GOME-2, and OMI.
Consistency between these new data sets and other ozone products (TOMS, SBUV, OMPS, HALOE, SAGE, MLS, and IASI) has been investigated, as well as between the total column and profile products.
Close interaction has been maintained with CEOS ACC, GCOS, IO3C and WMO Ozone Assessment.
See: http://www.esa-ozone-cci.org.

In mid-2016, the Sentinel 5 Precursor will be launched contributing to total ozone, ozone profiles and tropospheric ozone content. Sentinel 5 on-board Meteosat Third Generation (MTG) is expected to be launched around 2021 providing the continuity from Sentinel 5 P onwards.

2. Ozone Profiles from Nadir Instruments
2.a. NOAA Instruments on Polar Orbiters at 13:30.

The last remaining SBUV/2 on NOAA-19 POES is working well but its orbit has drifted past 2:00 PM Equator-crossing time and is headed even later. It has had some minor problems with one of the reflectivity channels but is continuing the long-term SBUV/2 ozone profile climate data record. This record has been updated with NOAA-19 SBUV/2 products through June 2014.

The OMPS Nadir Profiler on S-NPP is working very well. It is a stable instrument and on-board monitoring is providing calibration characterization that is expected to meet its stability requirement of 2% over the lifetime of the mission. We have added procedures to make stray light and wavelength scale correction using both on-ground characterization and in-orbit consistency checks to generate accurate level 1 products. Comparisons of chasing orbits (opportunistic formation flying that occurs approximately every 12 days) with NOAA-19 SVBUV/2 for the first three years show an ozone profile record that that will meets the 2% long-term stability and 5% accuracy targets. We expect to implement the V8 Ozone Profile algorithm in operations (in place of the current algorithm) and make soft calibration adjustments to the Level 1 product at the same time to produce a close to CDR quality operational product within the next year. (Aside: The adaptation of the V8 ozone profile algorithm for use with OMPS was supported by an NCDC project.) We expect the OMPS NP products to provide excellent continuity of the SBVU/2 record as they have controlled equator crossing times and an onboard system of working and reference diffusers.

The next OMPS Nadir Profiler will be launched on JPSS-1 in 2017. It has passed its pre-shipment review. We expect to increase the horizontal resolution by a factor of five (to ~50 KM at nadir but still restricted to a 250-km nadir swath) but maintain the accuracy and stability of the products. This will be followed by a third and final OMPS on JPSS-2.

2.b. Tropospheric Ozone Residuals.

The SBUV/2 and OMPS ozone profile product can be used to estimate the stratospheric contribution to the column ozone for the full globe by using assimilation or analysis methods. These have been combined with other estimates of total column ozone (e.g., daily maps) to produce estimates for tropospheric ozone by simple subtraction of the stratospheric columns from the total columns. Other more sophisticated methods using cloud slicing and deep convective clouds have also been used to provide long term tropospheric ozone records. The OMPS Nadir Mapper measurements match the quality and information content of the OMI measurements used in those studies, and so it should be able to continue those record.

2.c. Infrared ozone measurements.

The new hypespectral infrared instruments (US AIRS and CrIS, and European IASI) have information on ozone variations in the upper troposphere and lower stratosphere. The operational NOAA products from CrIS include ozone profile estimates. We are making a combined product using the SBUV/2 and OMPS NP Stratospheric information together with this IR information in the lower atmosphere to generate total ozone maps. We are developing a sequential retrieval using the OMPS NP maximum likelihood retrieval as an a priori for the CrIS maximum likelihood retrieval that will combine the complementary information content of the two sets of measurements.

2.d. ESA Instruments on Polar orbiter, NASA OMI and IASI on Metop.

Ozone_cci has produced long time series of ozone vertical profile measurements from multiple nadir sounding instruments. Per retrieval uncertainty estimates are provided in the products.

O_3 profiles from nadir instruments: GOME, SCIAMACHY, GOME-2, OMI and IASI.

Consistency between these new data sets and other ozone products (TOMS, SBUV, OMPS, HALOE, SAGE, MLS, and IASI) has been investigated, as well as between the total column and profile products.

Close interaction has been maintained with CEOS ACC, GCOS, IO3C and WMO Ozone Assessment.

See : http://www.esa-ozone-cci.org.

3. Ozone Profiles from Limb Instruments

3.a. NOAA Instruments on Polar Orbiters at 13:30.

The S-NPP OMPS Limb Profiler is performing well. The NASA OMPS Science Team is creating ozone profile products with 3-km or better vertical resolution down to the tropopause. NOAA has a project to implement this retrieval algorithm operationally. The next planned OMPS Limb Profiler is not expected until JPSS-2. Fortunately, while it is only a five-year mission on paper, the S-NPP spacecraft has fuel and power resources to operate for at least 12 more years, and the OMPS was designed for seven years reliability. This means that it is likely (>70%) that it will continue to function for 12 years as well. The current trending of instrument and detector degradation show manageable changes over that period.

3.b Other US Assets

NASA has plans to place a SAGE III instrument on the International Space Station in 2016. See http://sage.nasa.gov/SAGE3ISS/ . We expect to have good overlap between the measurements from the OMPS LP and the SAGE III. If for some reason the OMPS LP on S-NPP did not last until the launch of the second one on JPSS-2, we could use the ISS SAGE III as a transfer between the two.

3.c. ESA Instruments on Polar orbiter, and National Instruments.

Ozone_cci has produced long time series of ozone vertical profile measurements from multiple nadir sounding instruments. Per retrieval uncertainty estimates are provided in the products.

O_3 profiles from limb sounders: GOMOS, MIPAS, SCIAMACHY, OSIRIS, SMR and ACE/FTS (full-mission, harmonised, single instrument and merged data sets).

Consistency between these new data sets and other ozone products (TOMS, SBUV, OMPS, HALOE, SAGE, MLS, and IASI) has been investigated, as well as between the total column and profile products.

Close interaction has been maintained with CEOS ACC, GCOS, IO3C and WMO Ozone Assessment.

See : http://www.esa-ozone-cci.org.

References:

Adams, C., and Coauthors, 2013: Characterization of Odin-OSIRIS ozone profiles with the SAGE II dataset. *Atmos. Meas. Tech.*, **6**, 1447–1459, doi:10.5194/amt-6-1447-2013.

Adams, C., and Coauthors, 2013: Assessment of Odin-OSIRIS ozone measurements from 2001 to the present using MLS, GOMOS, and ozone sondes. *Atmos. Meas. Tech. Disc.*, **6**, 3819–3857, doi:10.5194/amtd-6-3819-2013.

Aschmann, J., J. P. Burrows, C. Gebhardt, A. Rozanov, R. Hommel, M. Weber, and A. M. Thompson, 2014: On the hiatus in the acceleration of tropical upwelling since the beginning of the 21st century. *Atmos. Chem. Phys.*, **14**, 12803–12814, doi:10.5194/acp-14-12803-2014.

Braesicke, P., O. See Hai, and A. Abu Samah, 2012: Properties of strong off-shore Borneo vortices: A composite analysis of flow pattern and composition as captured by ERA-Interim. *Atmos. Sci. Lett.*, **13**, 128–132, doi:10.1002/asl.372.

Cai, D., M. Dameris, H. Garny, and T. Runde, 2012: Implications of all season Arctic sea-ice anomalies on the stratosphere. *Atmos. Chem. Phys.*, **12**, 11819–11831, doi:10.5194/acp-12-11819-2012.

Chiou, E. W., and Coauthors, 2013: Comparison of profile total ozone from SBUV(v8.6) with GOME-type and ground-based total ozone for 16-yr period (1996 to 2011). *Atmos. Meas. Tech. Disc.*, **6**, 10081–10115, doi:10.5194/amtd-6-10081-2013

Coldewey-Egbers, M., D. G. Loyola R., P. Braesicke, M. Dameris, M. van Roozendael, C. Lerot, and W. Zimmer, 2014: A new health check of the ozone layer at global and regional scales. *Geophys. Res. Lett.*, **41**, 4363–4372, doi:10.1002/2014GL060212.

Dameris, M., and M. P. Baldwin, 2011: Impact of climate change on the stratospheric ozone layer. In *Stratospheric Ozone Depletion and Climate Change*, R. Muller, Ed., Royal Society of Chemistry, pp. 214–252, doi:10.1039/9781849733182.

Dameris, M., and P. Jöckel, 2013: Numerical modeling of climate-chemistry connections: Recent developments and future challenges. *Atmosphere*, **4**, 132–156, doi:10.3390/atmos4020132.

Dameris, M., and D. Loyola, 2012: Recent and future evolution of the stratospheric ozone layer. In *Atmospheric Physics*. Research Topics in Aerospace, E. Schumann, Ed., Springer, pp. 747–761, doi:10.1007/978-3-642-30183-4.

Dameris, M. and D. Loyola, 2011: Chemistry-climate connections – Interaction of physical, dynamical, and chemical processes in Earth atmosphere. In *Climate Change - Geophysical Foundations and Ecological Effects*, J. A. Blanco and H. Kheradmand, Eds., InTech, doi:10.5772/24210

De Laat, A. T. J., and M. van Weele, 2011: The 2010 Antarctic ozone hole: observed reduction in ozone destruction by minor sudden stratospheric warmings. *Scientific Reports*, **1**, 38, doi:10.1038/srep00038.

Ebojie, F., and Coauthors, 2013: Tropospheric column amount of ozone retrieved from SCIAMACHY limb-nadir-matching observations. *Atmos. Meas. Tech. Disc.*, **6**, 7811–7865, doi:10.5194/amtd-6-7811-2013.

Eckert, E., and Coauthors, 2013: Drift-corrected trends and periodic variations in MIPAS IMK/IAA ozone measurements. *Atmos. Chem. Phys. Disc.*, **13**, 17849–17900, doi:10.5194/acpd-13-17849-2013.

Gebhardt, C., and Coauthors, 2013: Stratospheric ozone trends and variability as seen by SCIAMACHY during the last decade. *Atmos. Chem. Phys. Disc.*, **13** , 11269–11313, doi:10.5194/acpd-13-11269-2013.

Hollmann, R., and Coauthors, 2013:. The ESA Climate Change Initiative: Satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, **94**, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Kyrölä, E., and Coauthors, 2013: Combined SAGE II-GOMOS ozone profile data set 1984–2011 and trend analysis of the vertical distribution of ozone. *Atmos. Chem. Phys. Disc.*, **13**, 10661–10700, doi:10.5194/acpd-13-10661-2013.

Laeng, A., and Coauthors, 2014:. Validation of MIPAS IMK/IAA V5R_O3_224 ozone profiles. *Atmos. Meas. Tech.*, **7**, 3971–3987, doi:10.5194/amt-7-3971-2014.

Laeng, A., and Coauthors, 2015: The ozone climate change initiative: Comparison of four Level-2 processors for the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS). *Remote Sens. Environ.*, **162**, 316–343, doi:10.1016/j.rse.2014.12.013.

Lerot, C., and Coauthors, 2013: Homogenized total ozone data records from the European sensors GOME/ERS-2, SCIAMACHY/Envisat and GOME-2/MetOp-A. *J. Geophys. Res. Atmos.*, **119**, 1639–1662, doi:10.1002/2013JD020831.

Loyola, D. G., and M. Coldewey-Egbers, 2012: Multi-sensor data merging with stacked neural networks for the creation of satellite long-term climate data records. *EURASIP J. Adv. Signal Process.*, **2012**, 91, doi:10.1186/1687-6180-2012-91

Mieruch, S., and Coauthors, 2012: Global and long-term comparison of SCIAMACHY limb ozone profiles with correlative satellite data (2002–2008). *Atmos. Meas. Tech.*, **5**, 771–788, doi:10.5194/amt-5-771-2012.

Mijling, B., O. N. E. Tuinder, R. F. van Oss, and R. J. van der A, 2010: Improving ozone profile retrieval from spaceborne UV backscatter spectrometers using convergence behaviour diagnostics. *Atmos. Meas. Tech.*, **3**, 1555–1568, doi:10.5194/amt-3-1555-2010.

Miles, G. M., R. Siddans, B. J. Kerridge, B. G. Latter, and N. A. D. Richards, 2015: Tropospheric ozone and ozone profiles retrieved from GOME-2 and their validation. *Atmos*. *Meas*. *Tech*., **8**, 385–398, doi:10.5194/amt-8-385-2015.

Miyazaki, K., H. J. Eskes, K. Sudo, M. Takigawa, M. van Weele, and K. F. Boersma, 2012: Simultaneous assimilation of satellite NO2, O3, CO, and HNO3 data for the analysis of tropospheric chemical composition and emissions. *Atmos*. *Chem*. *Phys*., **12**, 9545–9579, doi:10.5194/acp-12-9545-2012.

Rahpoe, N., C. von Savigny, M. Weber, A. V. Rozanov, H. Bovensmann, and J. P. Burrows, 2013: Error budget analysis of SCIAMACHY limb ozone profile retrievals using the SCIATRAN model. *Atmos*. *Meas*. *Tech*. *Disc*., **6**, 4645–4676, doi:10.5194/amtd-6-4645-2013.

Richards, N. A. D., and Coauthors, 2012: Source attribution and radiative impacts of the Mediterranean summertime ozone maximum: a satellite and model perspective. *Atmos*. *Chem*. *Phys*. *Disc*., **12**, 27219–27254, doi:10.5194/acpd-12-27219-2012.

Sioris, C. E., C. A. McLinden, V. E. Fioletov, C. Adams, J. M. Zawodny, A. E. Bourassa, and D. A. Degenstein, 2013: Trend and variability in ozone in the tropical lower stratosphere over 2.5 solar cycles observed by SAGE II and OSIRIS. *Atmos*. *Chem*. *Phys*. *Disc*., **13**, 16661–16697, doi:10.5194/acpd-13-16661-2013.

Sofieva, V. F., and Coauthors, 2013: Harmonized dataset of ozone profiles from satellite limb and occultation measurements. *Earth Syst*. *Sci*. *Data Disc*., **6**, 189–222, doi:10.5194/essdd-6-189-2013.

Sofieva, V. F., J. Tamminen, E. Kyrölä, T. Mielonen, P. Veefkind, B. Hassler, and G. E. Bodeker, 2013: A novel tropopause-related climatology of ozone profiles. *Atmos*. *Chem*. *Phys*. *Disc*., **13**, 21345–21382, doi:10.5194/acpd-13-21345-2013.

Sonkaew, T., C. von Savigny, K.-U. Eichmann, M. Weber, A. Rozanov, H. Bovensmann, and J. P. Burrows, 2011: Chemical ozone loss in Arctic and Antarctic polar winter/spring season derived from SCIAMACHY limb measurements 2002–2009. *Atmos*. *Chem*. *Phys*. *Disc*., **11**, 6555–6599, doi:10.5194/acpd-11-6555-2011.

Spurr, R., V. Natraj, C. Lerot, M. Van Roozendael, and D. Loyola, 2013: Linearization of the Principal Component Analysis method for radiative transfer acceleration: Application to retrieval algorithms and sensitivity studies. *J*. *Quant*. *Spectrosc*. *Rad*. *Trans*., **125**, 1–17, doi:10.1016/j.jqsrt.2013.04.002.

Valks, P., N. Hao, S. Gimeno Garcia, D. Loyola, M. Dameris, P. Jöckel, and A. Delcloo, 2014: Tropical tropospheric ozone column retrieval for GOME-2. *Atmos*. *Meas*. *Tech*., **7**, 2513–2530, doi:10.5194/amt-7-2513-2014.

Van Peet, J. C. A., R. J. van der A, O. N. E. Tuinder, E. Wolfram, J. Salvador, P. F. Levelt, and H. M. Kelder, 2013: Ozone ProfilE Retrieval Algorithm for nadir-looking satellite instruments in the UV-VIS. *Atmos*. *Meas*. *Tech*. *Disc*., **6**, 9061–9107, doi:10.5194/amtd-6-9061-2013.

Van Roozendael, M., and Coauthors, 2012: Sixteen years of GOME/ERS-2 total ozone data: The new direct-fitting GOME Data Processor (GDP) version 5—Algorithm description. *J*. *Geophys*. *Res*. *Atmos*., **117**, D03305. doi:10.1029/2011JD016471.

5.3.12 Aerosol Properties

Importance of this ECV

The IPCC has identified anthropogenic aerosols as the most uncertain climate forcing constituent. Aerosols influence the global radiation balance directly by scattering and absorbing radiation and indirectly through their effects on clouds. Some aerosol types scatter sunlight back to space, cooling the Earth; other types absorb solar or infrared radiation, warming the Earth. Sulphate, fossil fuel organic carbon, fossil fuel black carbon, biomass burning and mineral dust aerosols all have an important anthropogenic component and exert a significant direct radiative forcing. Key parameters for determining the direct radiative forcing are the aerosol optical properties (aerosol optical depth, the single scattering albedo, aerosol layer height, and aerosol extinction profile), which vary as a function of wavelength and relative humidity, and the atmospheric loading and geographic distribution of the aerosols in the horizontal and vertical, which change as a function of time. The indirect effect is the mechanism by which aerosols modify the microphysical and hence the radiative properties, amount and lifetime of clouds. The key factor is the effectiveness of an aerosol particle to act as a cloud condensation nucleus. Overall, both the direct and indirect aerosol forcings are negative, counteracting greenhouse gas forcing. The indirect is larger, but more uncertain.

Naturally occurring intense volcanic eruptions inject huge amounts of small particles into the stratosphere where they spread globally and remain for a year or more. They act as veil on the Earth reflecting sunlight back to space, which leads to reduced surface temperatures.

5.3.12.1 GCOS/CEOS Action A33; A.10.1 to A.10.4 (aerosol optical depth, aerosol single scattering albedo, aerosol layer height, and aerosol extinction profiles)

Action: Develop and implement a coordinated strategy to monitor and analyse the distribution of aerosols and aerosol properties. The strategy should address the definition of a GCOS baseline network or networks for *in situ* measurements, assess the needs and capabilities for operational and research satellite missions for the next two decades, and propose arrangements for coordinated mission planning.
Who: Parties' national services, research agencies and space agencies, with guidance from AOPC and in cooperation with WMO GAW and AERONET.
Time-Frame: Ongoing, with definition of baseline *in situ* components and satellite strategy by 2011.
Performance Indicator: Designation of GCOS baseline network(s). Strategy document, followed by implementation of strategy.
Annual Cost Implications: 10-30M US$ (20% in non-Annex-I Parties).

CEOS is working with the WCRP's GEWEX Data and Assessments Panel (GDAP) to develop a strategy for coordinating the aerosol community in a program to monitor and analyze the distribution of aerosol properties. GEWEX has recently completed a project – Global Aerosol Climatology Project (GACP) – to analyze satellite radiance measurements and field observations in order to infer the global distribution of aerosols, their properties, and their seasonal and interannual variations. A major outcome of this research effort was a 23-year global aerosol climatology compiled from channel-1 and -2 AVHRR data and supplemented by data from other satellites, field observations, and chemical-transport modeling.

The strategy will include the use of data from both operational and research missions. NASA's Glory research mission was to be a remote-sensing Earth-orbiting observatory designed to achieve two primary mission objectives. One was to collect data on the physical and chemical properties as well as the spatial and temporal distributions of aerosols. The other was to continue collection of total solar irradiance data for the long-term climate record. The mission ended March 4, 2011, when the spacecraft failed to reach orbit, due to a malfunctioning launch vehicle, following its launch from Vandenberg Air Force Base in California. However, NASA plans to launch an aerosol mission in the near future, and it will be one of the key satellite missions in the coordinated strategy for aerosols since it will measure the physical and chemical properties of aerosols as well as their spatial and temporal distributions.

2015 Update

Atmospheric aerosol was identified as an ECV by GCOS (2010) due to its important direct and indirect climate radiative forcing effects. The anthropogenic component of atmospheric aerosol is the most uncertain climate forcing constituent and the sign of its climate forcing is generally opposite to that of greenhouse gases. In the past two decades, significant advance in satellite and surface observations of aerosol optical and distribution properties (optical thickness, single scattering albedo, aerosol layer height, and aerosol extinction profiles) have been achieved due to dedicated aerosol observations from both space and surface.

Dedicated global satellite aerosol observations using multiple-spectral, -angles, and polarization retrieval techniques started in late 1990s and early 2000s from POLDER, SeaWiFS, MODIS, MISR, AATSR, GLI, OMI, etc (King et al., 1999) in order to better quantify aerosol loading (e.g., aerosol optical thickness), size parameter (e.g., aerosol angstrom exponent), aerosol type (e.g., dust and smoke), and absorbing characteristic (e.g., aerosol single scattering). CALIPSO lidar launched in the middle of 2000s on NASA A-Train constellation satellites (Winker et al., 2007) further added information of aerosol vertical distribution, such as aerosol layer height and aerosol extinction profiles. At the same time, GEWEX Global Aerosol Climatology Project (GACP) (Mishchenkoa et al., 2007) and NOAA aerosol climate data record (CDR) project (Zhao et al., 2008) reprocessed historical operational AVHRR satellite observations to generate more than 30-years aerosol climate datasets for aerosol trend detection. Dedicated satellite aerosol observations will continue and extend to next decade from both operational satellite missions (e.g., JPSS, GOES-R, EPS-SG, MTG) and research satellite missions (e.g., EarthCare, Sentinel-4/5, PACE). NOAA CDR Program will incorporate both current and future satellite aerosol observations into its aerosol climate dataset so that the aerosol climate data record will be extended to over 50-years long.

Globally coordinated surface aerosol observations have also been enhanced greatly in recently two decades due to the establishment of AErosol RObotic NETwork (AERONET) program (Holben et al., 1997), which is a federation of ground-based remote sensing aerosol networks established by NASA and PHOTONS (PHOtométrie pour le Traitement Opérationnel de

Normalisation Satellitaire) and is greatly expanded by collaborators from national/international agencies, institutes, universities, individual scientists, and partners. The program provides a long-term, continuous and readily accessible public domain database of aerosol optical, microphysical and radiative properties for aerosol research and characterization, validation of satellite retrievals, and synergism with other databases. The network currently contains more than 600 sites over the globe and imposes standardization of instruments, calibration, processing and distribution.

Both global observations and surface measurements dedicated to aerosol will be continued in parallel to next decade so that long term changes and variations of aerosol optical and distribution properties along with aerosol climate radiative forcing can be detected with less uncertainty and high confidence (Li et al., 2009).

References:

GCOS, Implementation plan for the global observing system for climate in support of the UNFCCC (2010 update). GCOS Rep. 138, 186 pp., 2010. [Available online at http://www.wmo.int/pages/prog/gcos/Publications/gcos-138.pdf.]

Holben B. N., T. F. Eck, I. Slutsker, D. Tanre, J. P. Buis, A. Setzer, E. Vermote, J. A. Reagan, Y. Kaufman, T. Nakajima, F. Lavenu, I. Jankowiak, and A. Smirnov, 1998: AERONET - A federated instrument network and data archive for aerosol characterization. *Remote Sens. Environ.*, **66**, 1–16.

Holben, B.N., D. Tanre, A. Smirnov, T.F. Eck, I. Slutsker, N. Abuhassan, W. Newcomb, and J.S. Schafer, 2001: An emerging ground-based aerosol climatology: Aerosol optical depth from AERONET. *J. Geophys. Res.*, **106**(D11), 12067–12097.

King, M. D., Y. J. Kaufman, D. Tanré, and T. Nakajima, 1999: Remote sensing of tropospheric aerosols from space: Past, present, and future. *Bull. Amer. Meteor. Soc.*, **80**, 2229–2259.

Li, Z., T. X.-P. Zhao, R. Kahn, M. Mishchenko, L. Remer, K.-H. Lee, M. Wang, I. Laszlo, T. Nakajima, and H. Maring, 2009: Uncertainties in satellite remote sensing of aerosols and impact on monitoring its long-term trend: a review and perspective. *Ann. Geophys.*, **27**, 2755–2770.

Mishchenkoa, M. I., I. V. Geogdzhayevb, B. Cairnsb, B. E. Carlsona, J. Chowdharyb, A. A. Lacisa, L. Liub, W. B. Rossowa, and L. D. Travis, 2007: Past, present, and future of global aerosol climatologies derived from satellite observations: A perspective. *J. Quant. Spectrosc. Radiative Transfer*, **106**, 325–347.

Winker, D. M., W. H. Hunt, and M. J. McGill, 2007: Initial performance assessment of CALIOP. *Geophys. Res. Lett.*, **34**, L19803, doi:10.1029/2007GL030135.

Zhao, T. X.-P., I. Laszlo, W. Guo, A. Heidinger, C. Cao, A. Jelenak, D. Tarpley, and J. Sullivan, 2008: Study of long-term trend in aerosol optical thickness observed from operational AVHRR satellite instrument. *J. Geophys. Res.*, **113**, D07201, doi:10.1029/2007JD009061.

5.3.12.2 GCOS/CEOS Action A34; SS: A.11.1

Action: Ensure continuity of products based on space-based measurement of the precursors (NO2, SO2, HCHO and CO in particular) of ozone and aerosols and derive consistent emission databases, seeking to improve temporal and spatial resolution.
Who: Space agencies, in collaboration with national environmental agencies and meteorological services.
Time-Frame: Requirement has to be taken into account now in mission planning, to avoid a gap in the 2020 timeframe.
Performance Indicator: Availability of the necessary measurements, appropriate plans for future missions, and derived emission data bases.
Annual Cost Implications: 10-30M US$ (10% in non-Annex-I Parties).

CEOS Entities:

- **CEOS Agency Leads:** CSA, ESA, NOAA
- **CEOS Agency Contributors**: CMA, CNES, DLR, JAXA/NIES/NICT, NASA
- **CEOS Coordination Mechanisms**: TBD

International Coordination Bodies: GAW

Associated Organizations: KNMI, University of Bremen, Netherlands Institute for Space Research (SRON), Global Emissions Inventory Activity (GEIA), Community Initiative for Emissions Research and Applications (CIERA) and Atmospheric Composition Change the European Network (ACCENT)**,** ESA Climate Change Initiative CCI (esa.cci.int)

Specific Deliverable #1:

- Maintain and continue generation of data records of tropospheric trace gases and aerosol information as retrieved from satellite measurements with clear error characterization.

Accuracy, stability, horizontal resolution, and vertical resolution

ECV: Aerosol Properties	**GCOS/CEOS Action A34**						
	Property (Tropospheric column)						
		O_3	Aerosol optical depth	NO_2	SO2	HCHO	CO
Accuracy	Target		Max (0.03; 10%)	max(20%; 0.03 DU)	max(30%; 0.04 DU)	max(30%; 0.04 DU)	20%
	Planned	25%	0.05	10-20%	20%	20%	25%
Stability (/decade)	Target		0.01	2%	5%	5%	2%
	Planned	1-3%	0.01	1%	1%	1%	2-3%
Horizontal resolution (km)	Target	10-15	5-10	5-10	5-10	5-10	5-10
	Planned	10-15	10-15	10-15	10-15	10-15	10-15
Vertical resolution	Target	Tropospheric column					
	Planned						

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

- EOS-AURA operations as long as instruments are functional (up to 2020)
- Decomissioning of ERS-2 in 2011
- Envisat operations to 2012 (mission terminated in 2012
- Metop-A operations to at least 2012
- Odin operations (with ESA support) to at least 2012
- ACE-FTS operations to at least 2012
- Launch of new satellites – *e.g.,* Metop-B 2012, Sentinel 5 precursor 2014, SAGE III-ISS 2014
- The ESA Climate Change Initiative initiated a Aerosol CCI Project to produce a suite of aerosol propreties data sets.

2015 Update

The Canadian Space Agency approved the continuation of the SCISAT mission through the end of 2015. The atmospheric chemistry experiment (ACE) Fourier transform infrared spectrometer is unique in its ability to make measurements of upper atmosphere chemistry in the trace gases responsible for ozone depletion. A complete review of this experiment can be found at the following website http://www.ace.uwaterloo.ca/index.html

Limb Sounding Mission Gap

Participants in the CEOS Atmospheric Chemistry Virtual Constellation meeting of 2014 recognize the significance of the looming gap in limb sounding data. Following the demise of the currently operating but aging instruments:

- MLS on Aura (microwave emission),
- SMR (microwave emission) on Odin,
- OSIRIS (limb scatter UV-Vis-NIR) on Odin,
- ACE-FTS (solar occultation IR) on SCISAT, and
- ACE-MAESTRO (solar occultation UV-Vis-NIR) on SCISAT,

the only limb sounding instruments will be:

- OMPS Limb Profiler on Suomi-NPP (limb scatter UV-Vis-NIR),
- SAGE-III/ISS (solar occultation & limb scatter UV-Vis-NIR, planned for 2016),
- OMPS Limb Profiler on JPSS-2 (limb scatter UV-Vis-NIR, planned for ~2021).

Specific Deliverable #2

Maximize use of existing sensors and develop a collaborative framework to advocate and facilitate near-term calibration/validation activities and other coordinated science team planning for near-term space-based missions with limb sounding capability (e.g., to include, but not limited to, Stratospheric Aerosol and Gas Experiment (SAGE) III-ISS and Sentinel 5-Precursor) to maximize scientific output.

Aerosol_cci is developing and delivering a suite of aerosol property data sets from the following European instruments:

- ATSR-2 and AATSR (1995-2012)
- AATSR-SCIAMACHY synergy (2002-2012)
- AATSR-MERIS synergy (2002-2012)
- SEVIRI (2004-2015)
- IASI (2006-2015; Saharan dust region only)
- POLDER-1, POLDER-2 and PARASOL (1997, 2003, and 2005-2014; prototype products over Africa)
- OMI (2004-2015)
- GOMOS (2002-2012)

Notably the (A)ATSR product accuracies have been considerably improved, and quantitative product uncertainties developed. Product accuracies are comparable with the best NASA products, and show lower bias in their long term trends (see figure below). Products are assessed as part of the international GEWEX Aerosol Assessment. Aerosol_cci has also initiated the International Satellite Aerosol Science Network (AeroSAT) which is closely linked with AeroCom, AerChemMIP, ICAP, IGAC/SPARC CCMI, and ACPC.

References:

De Leeuw, G., and Coauthors, 2013: Evaluation of seven European aerosol optical depth retrieval algorithms for climate analysis. *Remote Sens. Environ.*, 162, 295–315, doi:10.1016/j.rse.2013.04.023.

Hollmann, R., and Coauthors, 2013: The ESA Climate Change Initiative: Satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, 94, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Holzer-Popp, T., and Coauthors, 2013: Aerosol retrieval experiments in the ESA Aerosol_cci project. *Atmos. Meas. Tech.*, **6**, 1919–1957, doi:10.5194/amt-6-1919-2013.

Kolmonen, P., A.-M. Sundström, L. Sogacheva, E. Rodriguez, T. Virtanen, and G. de Leeuw, 2013: Uncertainty characterization of AOD for the AATSR dual and single view retrieval algorithms. *Atmos. Meas. Tech. Disc.*, **6**, 4039–4075, doi:10.5194/amtd-6-4039-2013.

Zieger, P., and Coauthors, 2012: Spatial variation of aerosol optical properties around the high-alpine site Jungfraujoch (3580 m a.s.l.). *Atmos. Chem. Phys.*, **12**, 7231–7249, doi:10.5194/acp-12-7231-2012.

Zieger, P., and Coauthors, 2011: Comparison of ambient aerosol extinction coefficients obtained from in-situ, MAX-DOAS and LIDAR measurements at Cabauw. *Atmos. Chem. Phys.*, **11**, 2603–2624, doi:10.5194/acp-11-2603-2011.

5.4 The Oceans

5.4.1 Introduction

Because of their high heat capacity, the oceans are often referred to as the 'fly wheel' of the climate system. The heat absorbed results in only small temperature changes. Heat absorbed at the ocean-atmosphere interface is slowly distributed to the deep ocean by mixing processes. Thus, the oceans act a heat reservoir. This characteristic buffers the climate system from change. The oceans also absorb a significant amount of the CO_2 emitted into the atmosphere. They influence the atmosphere – and vice versa – through transfers of heat, moisture, radiation, gases such as CO_2, and momentum at their interface. While the entire atmosphere is accessible for space, only the surface of the ocean is observable from satellites. Fortunately, one of the key climate variables affecting humankind – sea level – can be measured from satellites.

The ocean domain ECVs for which satellites make a major contribution are listed in Table 2 of Section 3.

5.4.2 Oceanic Domain – Surface: General

5.4.2.1 GCOS/CEOS Action O4; SS O.1

Action: Ensure coordination of contributions to CEOS Virtual Constellations for each ocean surface ECV, in relation to *in situ* ocean observing systems.
Who: Space agencies, in consultation with CEOS Virtual Constellation teams, JCOMM, and GCOS.
Time-Frame: Continuous.
Performance Indicators: Annually updated charts on adequacy of commitments to space-based ocean observing system from CEOS.
Annual Cost Implications: <1M US$ (Mainly by Annex-I Parties and implementation cost covered in Actions below).

The complete CEOS response to this action is under development.

2015 Update

CEOS has added a Sea Surface Virtual Constellation in late 2011. Other continuing CEOS ocean Virtual Constellations include Ocean Color Radiometry, Ocean Surface Topography, and Ocean Surface Vector Wind. Additional CEOS ocean virtual constellations will be considered if and when a need arises.

5.4.3 Sea Surface Temperature

Importance of this ECV

Sea surface temperature is a critical variable for the coupled atmosphere-ocean system. It controls the transfer of heat, water vapor, and CO_2 between the ocean and atmosphere. It influences weather – for example, the formation and development of tropical storms – and climate variations – for example, the El Niño-Southern Oscillation (ENSO) phenomena. It affects marine biodiversity and habitat properties (*e.g.,* coral-reef bleaching). Accurate knowledge of global sea surface temperature (SST) distribution and temporal variation at finer spatial resolution is needed as a key input to forecasting and prediction systems to constrain the modelled upper-ocean circulation and thermal structure at daily, seasonal, decadal and climatic timescales, for the exchange of energy between the ocean and atmosphere in coupled ocean-atmosphere models and as boundary conditions for ocean forecasting models. Well-defined and error quantified measurements of SST are also required for climate time series (in the form of climate data records) that can be analysed to reveal the role of the ocean in short and long term climate variability and to validate climate model predictions.

5.4.3.1 GCOS/CEOS Action O7; SS: O.1

Action: Continue the provision of best possible SST fields based on a continuous coverage-mix of polar orbiting IR and geostationary IR measurements, combined with passive microwave coverage, and appropriate linkage with the comprehensive *in situ* networks noted in O8.
Who: Space agencies, coordinated through CEOS, CGMS, and WMO Space Programme.
Time-Frame: Continuing.
Performance Indicator: Agreement of plans for maintaining a CEOS Virtual Constellation for SST.
Annual Cost Implications: 1-10M US$ (for generation of datasets) (Mainly by Annex-I Parties).

CEOS Entities:

- **CEOS Agency Leads:** ESA, NOAA
- **CEOS Agency Contributors:** EUMETSAT, JAXA, NASA, SANSA, UKSA, CSIRO
- **CEOS Coordination Mechanisms:** Sea Surface Temperature Virtual Constellation

International Coordination Bodies: Group for High Resolution Sea Surface Temperature (GHRSST), CGMS, WMO Space Programme

Associated Organizations: Bureau of Meterology (Australia), Japan Meterological Agency (JMA), CSIR (South Africa), European Centre for Medium Range Weather Forecasting (ECMWF, UK), IFREMER (France), Remote Sensing Systems (USA), Meteo France (France), The Met Office (UK), University of Miami (USA), University of Rhode Island (USA), Danish Meterological Institute (DMI, Denmark), Met. Norway (Norway), IMOS (Australia), IOOS (USA), Data Buoy Cooperation Panel (DBCP), University of Southampton (UK), University of Reading (UK), University of Leicester (UK), University of Cape Town (South Africa), University of Colorado (USA).

Specific Deliverable(s):

To meet GCOS SST requirements integrated analysis products are needed that take advantage of the strengths of each data stream (IR, PM and *in situ*) that make best use of our understanding of the limitations of each data stream, and that adjust for variations in the uncertainty from region to region. Meeting the GCOS global SST requirements is achievable through enhanced global deployment of existing technology and the improved calibration of satellite sensors, better validation of derived products and further advancement of blending methodologies capitalizing on the synergy benefit of different SST observations.

Specific deliverable #1:

Global coverage sea surface temperature data products, of climate quality, through analysis of multiple IR/MW satellite and in situ data sets.

Specific deliverable #2:

Regular consultation with the climate user community to understand the application of SST data sets in climate reseach and the requirements for the current and future generation of data products in support of these activities.

Specific deliverable #3:

Continued inter-comparison, inter-calibration and validation of satellite and in situ measurements in support of the SST ECV.

Specific deliverable #4:

On-going research and development of satellite data processing methods and algorithms in support of the SST ECV.

Accuracy, stability, horizontal resolution, and vertical resolution

ECV: Sea- surface temperature	GCOS/CEOS Action O7				
	Property				
		IR SST	Microwave SST	*In situ* SST	SST Analyses (Daily)
Accuracy (K)	Target	0.1	0.1	0.1	TBD
	Planned	0.3	0.42	0.23	0.2-0.5
	Current	~0.35	~0.5	~0.2	~0.3
Stability (K/decade)$	Target	0.03	0.03	0.03	TBD
	Planned	TBD	TBD	TBD	TBD
	Current	TBD	TBD	TBD	TBD
Horizontal resolution (km)*	Target	10	10	TBD	10
	Planned	25	25	EBD=2**	25-100
	Current	1	25	EBD=2**	1-100

* For in situ data, the measure is the Equivalent Buoy Density (EBD) required to reduce satellite bias to a defined figure quoted for number of buoys per 10 x 10 degree box.
** EBD = 2 based on NOAA requirements to reduce satellite bias to ~ 0.3 K (Zhang et al, 2006)
$ Stability is quoted in GCOS-154 for a target spatial scale of 100 km. The current system is capable of evaluating regional stability estimates only in the Tropical Pacific at scales of ~1000 km. Little if any data are available in high latitude regions for stability assessment.

Key activities and time frames to meet deliverables (2011 – 2015)

Adequacy/inadequacy of current holdings

SST data holdings are extensive and widely used, however further reprocessing is required to address known problems such as orbit and sensor calibration drifts, identification of clouds, estimation of uncertainties, and aerosol contamination.

Immediate action, partnerships and international coordination

1. Satellite SST data providers should take steps to make their L1b data available for use in the SST reprocessing and re-analysis community.
2. A concerted and immediate effort should be made to ensure the sustained continuity of passive microwave SST using a ~6.9 GHz channel. Steps should be taken to ensure that better accuracy and high spatial resolution are key design goals for future passive microwave satellite radiometers.
3. Maintain and enhance coverage of high frequency observations sufficient to resolve diurnal variability, provided at present by geostationary instruments and improve mechanisms for geostationary SST data exchange.
4. A concerted effort is required to develop a framework to provide robust uncertainty and bias estimates for *in situ* SST data sets that are used for satellite validation and L2 SST algorithm calibration.

5. Full, documented uncertainty information, presented using GCOS terminology and methods is required for all SST products.
6. Cloud screening of IR data is remains a significant challenge, despite nearly 30 years of activity, and failure to detect sub-pixel clouds remains the source of substantial uncertainty in IR satellite data sets. Further development of cloud clearing approaches is urgently required to improve the quality of IR SST FCDR.
7. The performance of IR satellite SST atmospheric correction algorithms in aerosol rich atmospheres must be improved (link to GCOS IP-10 Action A33)
8. More effort must be given to the definition and implementation of ice masking procedures and techniques in Polar Regions for satellite SST observations (link to GCOS IP-10 Action 019)
9. The performance of IR satellite SST atmospheric correction algorithms in polar atmospheres must be improved.
10. Steps should be taken to improve the treatment of side-lobe, ice and rain contamination of passive microwave measurements in the coastal zones.
11. Continue reprocessing of satellite data for providing a homogeneous global SST climate data record, in particular for all passive microwave data sets, geostationary and polar orbiting IR data sets (AVHRR data from 1981 to present requires reprocessing). A systematic framework in which satellite SST data sets can be regularly re-processed and uncertainty estimates provided is required (GCOS IP-10: Action C11). The system should foresee multiple re-processing of L0 (engineering) data through to L2 (geophysical) products to produce the best FCDR for each satellite sensor.
12. Sustain and augment the Argo profiling drifter network with better capability to resolve diurnal thermal stratification in the surface ocean. Argo profiling floats should be equipped with a capability to make detailed SST vertical profile measurements in the top 10 m of the ocean. (link to GCOS IP-10 Action O26)
13. Observing system experiments (OSE), sampling studies and, error analyses (such as the Potential Satellite Bias Error [PSBE]) should be an integral part in the design, development and operation of an integrated SST observing system suited to both near real time operations and climate data record production.
14. Continuing support is needed for efforts such as the GCOS SST/Sea Ice Working Group and the international Group for High-Resolution SST (GHRSST) Project (and associated CEOS SST Virtual Constellation that is now emerging – link to GCOS IP-10 Action O4) which attempts to make optimum use of satellite and *in situ* observations at the highest feasible space and time resolution whilst continuing to support efforts to improve the absolute accuracy of satellite SST measurements, and improving our understanding of the characteristics of the uncertainties.

2015 Update

Deliverable #1

- The ESA Climate Change Initiative (CCI) Sea Surface Temperature project (SST_cci, see http://www.esa-sst-cci.org/) is creating new Climate Data Records

(CDRs) of SST from satellite retrievals. The project began in August 2010 and has been extended until 2016. The project scope includes user requirements gathering, algorithm development, algorithm benchmarking, data production and validation, disseminating those data, and obtaining user feedback. ESA SST CCI products are designed as stable, low-bias SST data starting during 1991 and continuing to 31 December 2010 (referred to as the 'long term' product). Each SST has associated with it a total uncertainty estimate, and uncertainty estimates for various contributions to that total uncertainty. Future versions of the datasets now in development will span at least 1982–2016, better addressing the need in many climate applications for stable records of global SST that are at least 30 years in length. A user guide is available at http://www.esa-sst-cci.org/PUG/guide.htm. The datasets generated to date by SST CCI are available at http://www.esa-sst-cci.org and from the Centre for Environmental Data Archival via the page http://www.neodc.rl.ac.uk.

- NASA maintains a 1km resolution global coverage SST analysis called the Multiscale Ultrahigh Resolution (MUR) L4 analysis based on nighttime satellite SST observations from several satellite instruments. Data are available at https://podaac.jpl.nasa.gov/dataset/JPL-L4UHfnd-GLOB-MUR.
- NOAA also produces and provides the AVHRR Pathfinder SST Climate Data Record. Currently, Verison 5.2 is available, spanning 1981-2012 in Level 3 Collated form (Casey et al., 2011: http://dx.doi.org/10.7289/V5WD3XHB). In 2015 NOAA will release Version 5.3, which will span 1981-2013 and include Level 2, Level 3 Uncollated, and Level 3 Collated products. (http://www.nodc.noaa.gov/SatelliteData/pathfinder4km/)
- NOAA 1/4° daily Optimum Interpolation Sea Surface Temperature (or daily OISST, http://www.ncdc.noaa.gov/oisst) is an analysis constructed by combining observations from different platforms (satellites, ships, buoys) on a regular global grid. A spatially complete SST map is produced by interpolating to fill in gaps. Two analyses are produced: AVHRR-Only refers to the OISST that uses satellite SSTs only from from AVHRR and the AVHRR+AMSR uses AVHRR and additional data from AMSR-E, available from 2002 to 2011. The system also produces an anomaly field, an estimate of uncertainty and an estimate of sea ice concentration. A range of different data access points are available at http://www.ncdc.noaa.gov/oisst/data-access.
- A blended IR+MW satellite climate SST product has been developed by NASA/Remote Sensing Systems from Jume 2002 to present. A separate product covering the region 40N to 40S is available from January 1998. Data are available at http://www.remss.com/measurements/sea-surface-temperature.
- JAXA plan to produce a global coverage MW SST climate data product based on AMSRE and AMSR2.
- The EUMETSAT OSI-SAF plans to initiate MSG SEVIRI reprocessing of SST in 2015 in support of climate SST.
- The CEOS SST-VC is developing a white paper to describe a justified vision for

the SST satellite constellation to address the needs of the SST application community including climate research.

- The Copernicus Sentinel-3 Sea and Land Surface Temperature Radiometer (SLSTR) will make all L1b data sets available to the international community in a free and open manner.
- JMA released Himawari-8 L1 data to research community in March 2015, and data is (will be) released from four coordinating universities/agencies outside JMA, including JAXA.
- JAXA plan to distribute Himawari-8 L1 in July 2015, and release Himawari-8 SST in July or August 2015.
- JAXA released GPM/GMI SST to public in March 2015 through JAXA GHRSST server. JAXA also released GCOM-W/AMSR2 10-GHz SST to public in April 2015 as research product.
- ESA has run a series of studies to investigate the development of a new C-band passive microwave SST radiometer mission (called Microwat) having a real aperture of ~15 km. Both conical-scanning and intefreometer concepts have been studied. An optimal mission would be one flying in convoy with MetOp which would provide scatterometer and higher frequency passive moicrowave measuirments to complement the Micopwat C-band measurments.
- The following satellite launches are planned in the coming few years:

Mission	**Lead Agency**	**Expected Launch date**
Sentinel-3A SLSTR	ESA/EC/EUMETSAT	2015
Sentinel-3B SLSTR	ESA/EC/EUMETSAT	2017
JPSS-1 VIIRS	NOAA/NASA	2017
JPSS-2 VIIRS	NOAA/NASA	2021
GOES-R	NOAA	2016
GCOM-C SGLI	JAXA	2016
MSG-4 SEVIRI	EUMETSAT	2015
MetOp-C AVHRR/3	EUMETSAT	2018
Himawari-9 AHI	JMA	2016

Deliverable #2:

- The ESA SST_cci project has completed an exahstive user requirements survey for climate SST users thich is available at http://www.esa-sst-cci.org/PUG/documents.

- The GHRSST International Project Office is developing a User Requirements Survey for SST products including climate data users.
- ESA has initiated a project called Fiducial Measurements for Satellite SST (FRM4CEOS) to inter-calibrate ship-borne infrared radiometers used for satellite validation. This follows on from previous CEOS activities conducted at the University of Miami and will ensure SI traceability of rasdiometers. In addition, a study to consider how best to address the ttraceability of in situ data sources has also been initiated.
- The ESA SST_cci project held a dedicated workshop on the user requirements for uncertainty information for SST Climate Data Records at the Met Office, UK. A report is available at http://www.esa-sst-cci.org/PUG/workshop.htm, a signficiant conclusion being that many major users favour ensemble CDRs for SST.

Deliverable #3

- Coordination of SST activities at the international level is through the GHRSST/CEOS SST-VC meachanism. As part of this effort, the GHRSST Climate Data Record Technical Advisory Group (CDR-TAG) focuses on the creation of delayed mode Climate Data Record products with higher accuracy and consistency, linking GHRSST products to longer term climate records and historical SST reconstructions and enabling a sustained reprocessing capability for both individual satellite sensor data and multi-sensor blended reanalysis products. A specific Climate Data assessment Framework (CDAF, available at https://www.ghrsst.org/files/download.php?m=documents&f=140204110029-CDRTAGCDAFv104.pdf) has been developed to understand the suitability of GHRSST datasets for use as Climate Data Records (CDRs). The CDAF sets out how the CDR-TAG will discharge this responsibility by providing authoritative, comparable information about GHRSST datasets that will allow users to make their own judgment about use of the datasets as CDRs for their application.The SST_cci project has conducted a Climate Assessment Report based on a validation and assessment of SST_cci data products by the project and international user community available at http://www.esa-sst-cci.org/PUG/documents
- An inter-comparison of ten global SST analyses is provided by the Met Office, United Kingdom as a contribution to GHRSST/CEOS SST-VC activities at http://ghrsst-pp.metoffice.com/pages/latest_analysis/sst_monitor/daily/ens/. This system provides a means to investigate differences between various analysis methodologies, technical and practical choices made by different analysis designs. In future, a version of this system dedicated to SST climate reanalyses would be useful.

Deliverable #4

- GHRSST continues to coordinate various Technical Advisory Groups and Working grous (validation, inter-comparison, diurnal variability, high-latitude SST, Estimation and retreivals) that coordinate activities of SST research and development.

- A number of high-resolution drifting buoys reporting SST have been developed and deployed by the Data Buoy Cooperation Panel (DBCP) to assess their impact on satellite SST validation.
- A number of high-resolution Argo profiling floats have been developed and deployed (Anderson and Riser, 2014) allowing further research of diurnal variability.
- The ESA SST_cci has initiated research to investigate the use of Argo as a validation tool for SST climate data products.
- The GODAE Ocean View Science Team Observing system Evaluation Task Team (OSEval-TT) has performed several OSE including SST https://www.godae-oceanview.org/science/task-teams/observing-system-evaluation-tt-oseval-tt.

References:

Anderson, J., and S. Riser, 2014: Near-surface variability of temperature and salinity in the tropical and subtropical ocean: observations from profiling floats. *J. Geophys. Res. Oceans*, **119**, 7433–7448, doi:10.1002/2014JC010112.

Casey, K. S., and Coauthors, 2011: AVHRR Pathfinder version 5.2 level 3 collated (L3C) global 4km sea surface temperature. National Oceanographic Data Center, NOAA. Dataset. doi:10.7289/V5WD3XHB [21 May 2015]

Bulgin, C. E., S. Eastwood, O. Embury, C. J. Merchant, and C. Donlon, 2014: The sea surface temperature climate change initiative: Alternative image classification algorithms for sea-ice affected oceans. *Remote Sens. Environ.,* 162, 396–407, doi:10.1016/j.rse.2013.11.022.

Hollmann, R., and Coauthors, 2013: The ESA Climate Change Initiative: satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, **94**, 1541–1552, doi:10.1175/BAMS-D-11-00254.1

Merchant, C. J., and Coauthors, 2012: A 20 year independent record of sea surface temperature for climate from Along-Track Scanning Radiometers. *J. Geophys. Res. Oceans*, **117**, C12013, doi:10.1029/2012JC008400.

Merchant, C. J., and Coauthors, 2014: Sea surface temperature datasets for climate applications from Phase 1 of the European Space Agency Climate Change Initiative (SST CCI). *Geosci. Data J.*, **1**, 179–191, doi:10.1002/gdj3.20.

Zhang, H.-M., R. W. Reynolds, and T. M. Smith, 2006: Adequacy of the in situ observing system in the satellite era for climate SST. *J. Atmos. Oceanic Technol.*, **23**, 107–120, doi:10.1175/JTECH1828.1.

5.4.4 Sea Level

Importance of this ECV

Global sea level rise directly threatens coastal infrastructure through increased erosion, more frequent storm-surge flooding, and loss of habitat through wetlands inundation. It is particularly important to all low-lying land regions, including many small-island states. Horizontal gradients in sea level are indicators of ocean circulation. Globally sea level is driven by thermal expansion or contraction and through melting of glaciers and ice. Observations of sea level change can be used to infer the contribution from melting glaciers and ice sheets, if the effects of ocean expansion due to increasing heat content can be accounted for independently, for example from *in situ* ocean profile (Argo) observations.

5.4.4.1 GCOS/CEOS Action O10; SS: O.3

Action: Ensure continuous coverage from one higher-precision, medium-inclination altimeter (the "Reference Mission" and two medium-precision, higher-inclination altimeters ("Complementary Missions").
Who: Space agencies, with coordination through the CEOS Constellation for Ocean Surface Topography, CGMS, and the WMO Space Programme.
Time-Frame: Continuous.
Performance Indicator: Satellites operating, and provision of data to analysis centres.
Annual Cost Implications: 30-100M US$ (Mainly by Annex-I Parties).

CEOS Entities:

- **CEOS Agency Leads:** NASA, EUMETSAT
- **CEOS Agency Contributors**: NOAA, CNES, ISRO, CNSA, ESA
- **CEOS Coordination Mechanisms**: Ocean Surface Topography Virtual Constellation

International Coordination Bodies: TBD

Associated Organizations: SOA, NRL
ESA Climate Change Initiative CCI (esa.cci.int)

Specific Deliverable(s): Ocean surface topography field that integrates data from all available satellite altimeters to produce a climate record of global sea level.

Accuracy, stability, horizontal resolution, and vertical resolution

- **Accuracy requirements:** Requirements for this and the following three sections have been drawn from the following community-consensus document: *The Next 15 Years of Satellite Altimetry: Ocean Surface Topography User Requirements Document*, prepared by P. Escudier & J.-L. Fellous, CLS.DOS/NT/09.092, 46 pp, November 30, 2009. These requirements are for the "Reference Mission".

ECV: Sea level	**GCOS/CEOS Action O10**	
	Property	
	Sea level	
Accuracy (cm)	Target	2-4 mm (global mean); 1 cm over a grid mesh Regional: 1 cm (over grid mesh of 50-100 km
	Planned	3.4
Stability (mm/yr)	Target	<0.3 (global mean) <1 (for grid mesh of 50 -100 km)
	Planned	1.0

Horizontal resolution (km)	Target	50 global, 25 regional
	Planned	100
Vertical resolution (mm)	Target	0.1
	Planned	0.1

Key activities and time frames to meet deliverables (2011 – 2015)

- Launch of HY-2A in July 2011
- Launch of SARAL/AltiKa in 2012
- Launch of Jason-3 in 2014
- Launch of Sentinel-3A in 2013
- The ESA Climate Change Initiative initiated a Sea Level CCI Project to create a improved and homogeneous reprocessing of altimetry data from ERS-1, ERS-2, Envisat, TOPEX/Poseidon, Jason-1, Jason-2, GeoSat and GFO.

2015 Update

The major achievements realised by the Sea_Level CCI project consist of:

(1) improved and homogeneous reprocessing of altimetry data from ERS-1, ERS-2, Envisat, TOPEX/Poseidon, Jason-1, Jason-2, GeoSat and GFO (plus additional data from CryoSat, Altika, Sentinel-3 and Jason-3, the two former in preparation, the two latter depending on launch date) based on new orbit solutions, improved wet tropospheric corrections and tidal corrections, etc., with the goal to provide an accurate 23-year long (1993-2015) sea level record (FCDR and the ECVs global mean and gridded sea level time series),
(2) production of formal errors for all the products, with a comprehensive error characteristic analysis.
(3) investigation of specific technical issues, such as Arctic sea-level during sea-ice minima, coastal sea-level change, etc.

By combining the Sea Level_CCI products with other CCI ECVs (glaciers, ice sheets, sea surface temperature, etc.), improved sea level budget studies have been performed at global and regional scales, allowing estimates of unknown -or poorly known- contributions (e.g., the deep ocean heat uptake and its role in the current 'hiatus' or the land water storage change due to human activities). Products were developed in the framework of the Ocean Surface Topography Science Team (OSTST) and the Global Sea Level Observing System (GLOSS).
See: http://www.esa-sealevel-cci.org

See also CEOS ocean surface topography virtual constellation link at http://ceos.org/ourwork/virtual-constellations/ost/.

References:

Ablain, M., and Coauthors, 2014: Improved sea level record over the satellite altimetry era (1993–2010) from the Climate Change Initiative Project. *Ocean Sci. Disc.*, **11**, 2029–2071, doi:10.5194/osd-11-2029-2014.

Ablain, M., A. Cazenave, G. Valladeau, and S. Guinehut, 2009: A new assessment of the error budget of global mean sea level rate estimated by satellite altimetry over 1993–2008. *Ocean Science*, **5**, 193–201, doi:10.5194/os-5-193-2009.

Ablain, M., S. Philipps, M. Urvoy, N. Tran, and N. Picot, 2012: Detection of long-term instabilities on altimeter backscatter coefficient thanks to wind speed data comparisons from altimeters and models. *Marine Geod.*, **35**(sup1), 258–275. doi:10.1080/01490419.2012.718675

Cazenave, A., H.-B. Dieng, B. Meyssignac, K. von Schuckmann, B. Decharme, and E. Berthier, 2014: The rate of sea-level rise. *Nature Climate Change*, **4**, 358–361, doi:10.1038/nclimate2159.

Cazenave, A., and Coauthors, 2012:. Estimating ENSO influence on the global mean sea level, 1993–2010. *Marine Geod.*, **35**(sup1), 82–97, doi:10.1080/01490419.2012.718209.

Couhert, A., and Coauthors, 2015: Towards the 1mm/y stability of the radial orbit error at regional scales. *Adv. Space Res.*, **55**, 2–23, doi:10.1016/j.asr.2014.06.041.

Dieng, H. B., H. Palanisamy, A. Cazenave, B. Meyssignac, and K. von Schuckmann, 2015: The sea level budget since 2003: Inference on the deep ocean heat content. *Surv. Geophys.*, **36**, 209–229, doi:10.1007/s10712-015-9314-6.

Feng, X., M. N. Tsimplis, G. D. Quartly, and M. J. Yelland, 2014: Wave height analysis from 10 years of observations in the Norwegian Sea. *Continental Shelf Res.*, **72**, 47–56, doi:10.1016/j.csr.2013.10.013.

Feng, X., M. N. Tsimplis, M. J. Yelland, and G. D. Quartly, 2014: Changes in significant and maximum wave heights in the Norwegian Sea. *Global Planet. Change*, **113**, 68–76, doi:10.1016/j.gloplacha.2013.12.010.

Henry, O., M. Ablain, B. Meyssignac, A. Cazenave, D. Masters, S. Nerem, and G. Garric, 2013: Effect of the processing methodology on satellite altimetry-based global mean sea level rise over the Jason-1 operating period. *J. Geodesy*, **88**, 351–361, doi:10.1007/s00190-013-0687-3.

Hollmann, R., and Coauthors, 2013. The ESA Climate Change Initiative: Satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, **94**, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Johannessen, J. A., and Coauthors, 2014: Toward improved estimation of the dynamic topography and ocean circulation in the high latitude and Arctic Ocean: The Importance of GOCE. *Surv. Geophys.*, **35**, 661–679, doi:10.1007/s10712-013-9270-y.

Legeais, J.-F., M. Ablain, and S. Thao, 2014: Evaluation of wet troposphere path delays from atmospheric reanalyses and radiometers and their impact on the altimeter sea level. *Ocean Science*, **10**, 893–905, doi:10.5194/os-10-893-2014.

Masters, D., R. S. Nerem, C. Choe, E. Leuliette, B. Beckley, N. White, and M. Ablain, 2012: Comparison of global mean sea level time series from TOPEX/Poseidon, Jason-1, and Jason-2. *Marine Geod*., **35**(sup1), 20–41, doi:10.1080/01490419.2012.717862.

Ollivier, A., Y. Faugere, N. Picot, M. Ablain, P. Femenias, and J. Benveniste, 2012: Envisat ocean altimeter becoming relevant for mean sea level trend studies. *Marine Geod*., **35**(sup1), 118–136, doi:10.1080/01490419.2012.721632.

Palanisamy, H., A. Cazenave, T. Delcroix, and B. Meyssignac, 2015: Spatial trend patterns in the Pacific Ocean sea level during the altimetry era: the contribution of thermocline depth change and internal climate variability. *Ocean Dynamics*, **65**, 341–356, doi:10.1007/s10236-014-0805-7.

Palanisamy, H., A. Cazenave, B. Meyssignac, L. Soudarin, G. Wöppelmann, and M. Becker, 2014: Regional sea level variability, total relative sea level rise and its impacts on islands and coastal zones of Indian Ocean over the last sixty years. *Global Planet*. *Change*, **116**, 54–67, doi:10.1016/j.gloplacha.2014.02.001.

Passaro, M., P. Cipollini, S. Vignudelli, G. D. Quartly, and H. M. Snaith, 2014: ALES: A multi-mission adaptive subwaveform retracker for coastal and open ocean altimetry. *Remote Sens*. *Environ*., **145**, 173–189. doi:10.1016/j.rse.2014.02.008.

Prandi, P., M. Ablain, A. Cazenave, and N. Picot, 2012: A new estimation of mean sea level in the Arctic Ocean from satellite altimetry. *Marine Geod*., **35**(sup1), 61–81, doi:10.1080/01490419.2012.718222.

Rudenko, S., and Coauthors, 2014: Influence of time variable geopotential models on precise orbits of altimetry satellites, global and regional mean sea level trends. *Adv*. *Space Res*., **54**, 92–118, doi:10.1016/j.asr.2014.03.010.

Valladeau, G., J. F. Legeais, M. Ablain, S. Guinehut, and N. Picot, 2012: Comparing altimetry with tide gauges and Argo profiling floats for data quality assessment and mean sea level studies. *Marine Geod*., **35**(sup1), 42–60, doi:10.1080/01490419.2012.718226.

5.4.5 Sea Surface Salinity

Importance of this ECV

Sea surface salinity (SSS) together with sea temperature determines the density of seawater; cold and salty water being denser than warm and fresh water. In some regions (*e.g.,* the Arctic), cold and salty water fosters the formation of deep water, which is the process that triggers the so-called thermohaline circulation. This "conveyor belt"-like circulation is an important component of the Earth's heat redistribution, and is crucial in regulating weather and climate.

5.4.5.1 GCOS/CEOS Action O12; SS: O.2

Action: Research programmes should investigate the feasibility of utilizing satellite data to help resolve global fields of sea surface salinity.
Who: Space agencies, in collaboration with the ocean research community.
Time-Frame: Feasibility studies complete by 2014.
Performance Indicator: Reports in literature and to OOPC.
Annual Cost Implications: 1-10M US$ (Mainly by Annex-I Parties).

ECV: Sea surface salinity	GCOS/CEOS Action O12	
	Property	
	Sea surface salinity	
Accuracy (cm)	Target	0.05 psu
	Planned	TBD
Stability (mm/yr)	Target	0.05 psu
	Planned	TBD
Horizontal resolution (km)	Target	100
	Planned	TBD
	Planned	TBD

ESA's Soil Moisture and Ocean Salinity (SMOS) mission, launched in 2009, was the first satellite with an instrument to measure sea surface salinity (SSS). SMOS was followed by the launch of the joint CONAE/NASA Aquarius/SAC-D in 2011. CEOS will work with the NASA and ESA science teams and the U.S. Climate Variability and Predictability Research Program (CLIVAR) Salinity Working Group to organize research programs involving the ocean research community to investigate the feasibility of utilizing satellite data to help resolve global fields of sea surface salinity. Products from the research satellite missions SMOS and Aquarius/SAC-D will enable development and demonstration of sea-surface salinity measurements from space.

One of the goals of the research is the design of an integrated sea surface salinity observing and analysis system that represents a balance of *in situ* and satellite instruments.

The complete CEOS response to this action is under development.

2015 Update

Sea surface salinity missions now in orbit include the ESA Soil Moisture and Ocean Salinity (SMOS) launched in 2009 and the NASA Aquarius launched in 2011. ESA and NASA have funded research programs using these data and producing global fields of sea surface salinity merging all available observations. The results of these programs were summarized in an ocean salinity meeting in November 2014 (http://www.oceansalinityscience2014.org/)

5.4.6 Ocean Colour

Importance of this ECV

Ocean biology and the carbon cycle are linked. Remote sensing measurements of ocean colour (*i.e.,* the detection of phytoplankton pigments) provide the only global-scale observations of the biology and productivity of the ocean's surface layer. Phytoplankton are microscopic plants that live in the ocean, and like terrestrial plants, they contain the pigment chlorophyll, which gives them their greenish colour. Different shades of ocean colour reveal the presence of differing concentrations of sediments, organic materials and phytoplankton.

Ocean biology is important not only for understanding ocean productivity and biogeochemical cycling, but also because of its impact on oceanic CO_2 and the flux of carbon from the surface to the deep ocean. Over time, organic carbon settles in the deep ocean, a process referred to as the 'biological pump'. CO_2 system measurements, integrated with routine ocean colour and ecological/biogeochemical observations, are critical for understanding the interactions between oceanic physics, biology, chemistry and climate.

5.4.6.1 GCOS/CEOS Action O15; SS: O.6.1

Action: Implement continuity of ocean colour radiance datasets through the plan for an Ocean Colour Radiometry Virtual Constellation.
Who: CEOS space agencies, in consultation with IOCCG and GEO.
Time-Frame: Continuing.
Performance Indicator: Global coverage with consistent sensors operating according to the GCMPs; flow of data into agreed archives.
Annual Cost Implications: 30-100M US$ (10% in non-Annex-I Parties).

Associated Organizations: ESA Climate Change Initiative CCI (esa.cci.int)

Specific Deliverable(s):
The FCDR for ocean color is the time series of calibrated top-of-atmosphere (TOA) radiances which are then corrected for the atmospheric contribution to the signal, to obtain the water-leaving radiance suite from which data products such as chlorophyll-*a* concentration are derived. The most important ocean color ECV products are the normalized water leaving radiances and chlorophyll-*a* concentration. Other products are in development such as colored, dissolved organic matter and particulate backscatter (used to estimate total suspended material). Ocean color radiances (OCR) products are the only measurements related to biological and biogeochemical processes in the ocean that can be routinely obtained at ocean basin and global ocean scales. These products are used to assess ocean ecosystem health and productivity, to understand the role of the oceans in the global carbon cycle, to manage living marine resources, and to quantify the impacts of climate variability and change.

Accuracy, stability, horizontal resolution, and vertical resolution

Accuracy: 5% for water leaving radiances (for the blue and green wavelengths) and 30% for chlorophyll in the concentration range 0.01-10 mg m^-3 in Case 1 waters. Planned, next generation, OCR sensors (*e.g.,* Pre-Aerosol, Clouds, and ocean Ecosystem [PACE] and Aerosol, Clouds, and ocean Ecosystem [ACE]) aim at achieving improved accuracy (i.e. < than 5% for water leaving radiance and 20% for chlorophyll "a" concentration). The OCR ECV time-series will undoubtedly benefit from this additional capability.

ECV: Ocean colour	GCOS/CEOS Action O15		
	Property		
		Water leaving radiance	Chlorophyll
Accuracy (%)	Target	5 (blue/green wavelengths)	30
	Planned	5	30
Stability (%/decade)	Target	0.5	3
	Planned	TBD	TBD
Horizontal resolution (km)	Target	4	30
	Planned	4	4

Key activities and time frames to meet deliverables (2011 – 2015)

- Provide, through the Ocean Colour Radiometry Virtual Constellation (OCR-VC), long time series of calibrated OCR at key wavelength bands from measurements obtained from multiple satellites. OCR-VC activities will include calibration, validation, merging of satellite and *in situ* data, product generation, as well as development and demonstrations of new and improved applications. Examples and prototypes of programs the OCR-VC will require to meet its objectives include the Sensor Intercomparison for Marine Biological and Interdisciplinary Ocean Studies (SIMBIOS) (NASA), GlobColour (ESA), ChloroGIN (Partnership for Observation of the Global Oceans [POGO]-GEO-Global Ocean Observing System [GOOS]) and Societal Applications in Fisheries and Aquaculture using Remotely-Sensed Imagery (SAFARI) (CSA/GEO) projects.
- Define and implement an international initiative to establish an integrated network for sensor inter-comparison and uncertainty assessment for Ocean Colour Radiometry.
- Consolidate and assess a global OCR ECV based on cross-calibrated OCR FCDR from multiple satellites which should be merged to provide an ECV product of water-leaving radiances beginning with the visible spectrum.
- The ESA Climate Change Initiative initiated an Ocean Colour CCI Project to deliver Water-leaving radiances and Chlorophyll-a concentration.

2015 Update

The CEOS OCR-VC continues to actively coordinate Space Agency plans for instrumentation from both polar and geostationary satellites. The OCR-VC works in collaboration with the International Ocean Colour Coordinating Group (IOCCG) and has recently updated plans for ocean color sensors from geostationary orbit (IOCCG Report 12), sensor requirements (IOCCG Report 13), and in flight calibration (IOCCG Report 14) all available from the IOCCG.org web site.

With respect to ECV generation, International efforts to produce time series of ECVs include:

- NASA-GSFC: Lw and Chl time series from SeaWiFS, Aqua, Terra, MERIS
- MEaSUREs (NASA): inherent optical properties (IOPs) from SeaWiFS, Aqua, MERIS
- GLOBColour (ESA): time series of merged data from SeaWiFS, Aqua, MERIS
- ESA's CCI program: new (Dec 2013) merged and bias corrected times series from

MERIS, MODIS, SeaWiFS with associated per-pixel uncertainty information. The following ECV products are being delivered from a multi-mission combination of SeaWiFS, MODIS/Aqua, MERIS, and eventually VIIRS and Sentinel-3 OLCI observations. The following products are being delivered, covering the time period 1997-2015:

- Water-leaving radiances (412, 443, 490, 510, 555 and 670 nm)
- Chlorophyll-a concentration, diffuse attenuation coefficient (490 nm) and inherent optical properties (412, 443, 490, 510, 555 and 670 nm).

Additional tests are performed on earlier CZCS data from 1978-1986. The products cover Case 1 waters (oceanic) and plans are underway to develop prototype ECV products for Case 2 (coastal) waters.

Work is being conducted in consultation with the International Ocean Colour Coordinating Group and the OCR Virtual Constellation. Close collaboration with the NASA Ocean Biology Processing Group and NASA MEaSURES project has been maintained throughout.

See: www.esa-oceancolour-cci.org

Next steps for progress in climate uses of ocean color include:

- Evaluate differences among existing OCR ECV products
- Recommend comparison/evaluation metrics
- Identify opportunities for further improvement
- Encourage convergence on a cooperative approach for a common product assessment or common processing approach

References:

Brewin, R. J. W., G. Dall'Olmo, S. Sathyendranath, and N. J. Hardman-Mountford, 2012: Particle backscattering as a function of chlorophyll and phytoplankton size structure in the open-ocean. *Optics Express*, **20**, 17632–17652, doi:10.1364/OE.20.017632.

Brewin, R. J. W., E. Devred, S. Sathyendranath, S. J. Lavender, and N. J. Hardman-Mountford, 2011: Model of phytoplankton absorption based on three size classes. *Applied Optics*, **50**, 4535–4549, doi:10.1364/AO.50.004535.

Brewin, R. J. W., D. E. Raitsos, Y. Pradhan, and I. Hoteit, 2013: Comparison of chlorophyll in the Red Sea derived from MODIS-Aqua and in vivo fluorescence. *Remote Sens. Environ.*, **136**, 218–224, doi:10.1016/j.rse.2013.04.018.

Brewin, R. J. W., and Coauthors, 2015: The Ocean Colour Climate Change Initiative: III. A round-robin comparison on in-water bio-optical algorithms. *Remote Sens. Environ.*, **162**, 271–294, doi:10.1016/j.rse.2013.09.016.

Brotas, V., and Coauthors, 2013: Deriving phytoplankton size classes from satellite data: Validation along a trophic gradient in the eastern Atlantic Ocean. *Remote Sens. Environ.*, **134**, 66–77, doi:10.1016/j.rse.2013.02.013.

Ciavatta, S., R. Torres, V. Martinez-Vicente, T. Smyth, G. Dall'Olmo, L. Polimene, and J. I.Allen, 2014: Assimilation of remotely-sensed optical properties to improve marine biogeochemistry modelling. *Progr. Oceanogr.*, **127**, 74–95, doi:10.1016/j.pocean.2014.06.002.

Ciavatta, S., R. Torres, S. Saux-Picart, and J. I. Allen, 2011: Can ocean color assimilation improve biogeochemical hindcasts in shelf seas? *J. Geophys. Res. Oceans*, **116**, C12043, doi:10.1029/2011JC007219.

Devred, E., S. Sathyendranath, V. Stuart, and T. Platt, 2011: A three component classification of phytoplankton absorption spectra: Application to ocean-color data. *Remote Sens. Environ.*, **115**, 2255–2266, doi:10.1016/j.rse.2011.04.025.

Garcia-Soto, C., and Coauthors, 2012: The influence of the Indian Ocean Dipole on interannual variations in phytoplankton size structure as revealed by Earth Observation. *Deep Sea Res. Part II*, **77**, 117–127, doi:10.1016/j.dsr2.2012.04.009.

Hollmann, R., and Coauthors, 2013: The ESA Climate Change Initiative: Satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, **94**, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Mélin, F., and G. Sclep, 2015: Band shifting for ocean color multi-spectral reflectance data. *Optics Express*, **23**, 2262–2279, doi:10.1364/OE.23.002262.

Mélin, F., and V. Vantrepotte, 2015: How optically diverse is the coastal ocean? *Remote Sens. Environ.*, **160**, 235–251, doi:10.1016/j.rse.2015.01.023.

Mélin, F., and Coauthors, 2011: Assessment of MERIS reflectance data as processed with SeaDAS over the European seas. *Optics Express*, **19**, 25657–25671, doi:10.1364/OE.19.025657.

Melin, F., G. Zibordi, B. N. Holben, 2013: Assessment of the aerosol products from the SeaWiFS and MODIS ocean-color missions. *IEEE Geosci. Remote Sens. Lett.*, **10**, 1185–1189, doi:10.1109/LGRS.2012.2235408.

Racault, M.-F., C. Le Quéré, E. Buitenhuis, S. Sathyendranath, and T. Platt, 2012: Phytoplankton phenology in the global ocean. *Ecolog. Indicators*, **14**, 152–163, doi:10.1016/j.ecolind.2011.07.010.

Raitsos, D. E., Y. Pradhan, R. J. W. Brewin, G. Stenchikov, and I. Hoteit, 2013: Remote sensing the phytoplankton seasonal succession of the Red Sea. *PloS One*, **8(6)**, e64909, doi:10.1371/journal.pone.0064909.

Roy, S., D. S. Broomhead, T. Platt, S. Sathyendranath, and S. Ciavatta, 2012: Sequential variations of phytoplankton growth and mortality in an NPZ model: A remote-sensing-based assessment. *J. Marine Syst.*, **92**, 16–29, doi:10.1016/j.jmarsys.2011.10.001.

Sathyendranath, S., and Coauthors, 2012: Ocean Colour Climate Change Initiative — Approach and initial results. In *2012 IEEE International Geoscience and Remote Sensing Symposium*, IEEE, pp. 2024–2027, doi:10.1109/IGARSS.2012.6350979.

Saux Picart, S., S. Sathyendranath, M. Dowell, T. Moore, and T. Platt, 2014: Remote sensing of assimilation number for marine phytoplankton. *Remote Sens. Environ.*, **146**, 87–96, doi:10.1016/j.rse.2013.10.032.

Steinmetz, F., P.-Y. Deschamps, and D. Ramon, 2011: Atmospheric correction in presence of sun glint: application to MERIS. *Optics Express*, **19**, 9783–800, doi:10.1364/OE.19.009783.

Zhai, L., and Coauthors, 2012: Phytoplankton phenology and production around Iceland and Faroes. *Continental Shelf Res*., **37**, 15–25, doi:10.1016/j.csr.2012.01.013.

Zhai, L., C. Tang, T. Platt, and S. Sathyendranath, 2011: Ocean response to attenuation of visible light by phytoplankton in the Gulf of St. Lawrence. *J*. *Marine Syst*., **88**, 285–297, doi:10.1016/j.jmarsys.2011.05.005.

Zibordi, G., B. Holben, F. Mélin, D. D'Alimonte, J.-F. Berthon, I. Slutsker, and D. Giles, 2010: AERONET-OC: An overview. *Canadian J*. *Remote Sens*., **36**, 488–497, doi:10.5589/m10-073.

5.4.7 Sea Ice

Importance of this ECV

Sea ice is a feedback variable in climate change. With global warming, ice, which reflects solar radiation, melts and is replaced by open ocean, which absorbs sunlight, thus amplifying the initial warming. The presence of ice affects the heat and moisture fluxes between the ocean and atmosphere. Sea ice also affects the movement of ocean waters. When sea ice forms, most of the salt is pushed into the ocean water below the ice. The higher salinity results in a higher sea water density. The cold, dense, polar water sinks and moves along the ocean bottom toward the equator, while warm water from mid-depth to the surface travels from the equator toward the poles. Variations in sea ice extent can modify this oceanic global "conveyor-belt" circulation, with profound effects on climate. As a climate impact variable, sea ice extent constrains marine transportation in high latitude regions.

5.4.7.1 GCOS/CEOS Action O19; SS: O.5

Action: Ensure sustained satellite-based (microwave, SAR, visible and IR) sea-ice products.
Who: Parties' national services, research programmes and space agencies, coordinated through the WMO Space Programme and Global Cryosphere Watch, CGMS, and CEOS; National services for *in situ* systems, coordinated through WCRP CliC and JCOMM.
Time-Frame: Continuing.
Performance Indicator: Sea-ice data in International Data Centres.
Annual Cost Implications: 1-10M US$ (Mainly by Annex-I Parties).

Associated Organizations: ESA Climate Change Initiative CCI (esa.cci.int)

ECV: Sea ice	GCOS/CEOS Action O19					
	Property					
		SI concentration	SI extent/edge	SI thickness	SI drift
Accuracy	Target	5% ice area fraction	5 km	0.1 m	1 km/day
	Planned	TBD	TBD	TBD	TBD
Stability (/decade)	Target	5%	TBD	TBD	TBD
	Planned	TBD	TBD	TBD	TBD
Horizontal resolution (km)	Target	10-15	1-5	25	5
	Planned	TBD	TBD	TBD	TBD

Key activities and time frames to meet deliverables (2011 – 2015)

- The ESA Climate Change Initiative initiated an Ocean Colour CCI Project to deliver Water-leaving radiances and Chlorophyll-a concentration.

The complete CEOS response to this action is under development.

2015 Update

The Sea Ice CCI project has developed and processed the following consistent multi-mission merged sea-ice ECV products:

- Sea ice concentration based on SSM/I (F10, F11, F13, F14, F15) (1992-2008) and AMSR-E (2002-2011);
- Winter Arctic sea ice thickness and freeboard from Envisat RA-2 (2002-2012) and Antarctic freeboard for Envisat RA-2 (2002-2012)

This is being complemented by:

- Sea ice concentration based on AMSR-E (2002-2011) and AMSR2 (2013-2015);
- Arctic sea ice thickness and freeboard and Antarctic freeboard from ERS-1 RA (1993-2000), ERS-2 RA (1995-2003), Envisat RA-2 (2002-2012), Cryosat-2 SIRAL2 (2010 ->) and Arctic thin ice sea ice thickness from SMOS (2009 ->)
- Sea ice drift: algorithm inter-comparison and product specifications for a new sea ice ECV.

The data are available at the Integrated Climate Data Center (ICDC) in Hamburg: http://icdc.zmaw.de/esa-cci_sea-ice-ecv0.html?&L=1
Note: The Sea Ice Concentration products are developed in collaboration with EUMETSAT OSISAF.
See: http//esa-cci.nersc.co

Progress on Action O19: Ensure sustained satellite-based (microwave, SAR, visible and IR) sea-ice products

Primary sea ice products derived from satellites are concentration, extent/edge, thickness, and motion. Concentration, extent, and motion have primarily been derived from passive microwave instruments. These have a long-term legacy (since late 1978 for multichannel radiometers) and thus can provide information on climate trends and multidecadal variability. In addition, the instruments can collect data during night conditions and through most clouds, providing complete daily coverage. However, they do have substantial limitations.

First, passive microwave energy from the surface is modified by the atmosphere, particularly water vapor and liquid water. This affects the accuracy of uncertainty retrievals. Some work has been done to develop atmospheric corrections (e.g., Markus and Cavalieri, 2000), but the effectiveness of these has not yet been well validated. Another significant limitation is that during summer surface melt water and melt ponds on the ice are seen as reduced concentration. Finally, thin ice (less than ~30 cm) tends to be underestimated due to emission from below the ice surface; this limits accuracy near the ice edge during the growth season and in leads and polynyas (e.g., Meier, 2005).

Fortunately, the Arctic atmosphere is relatively dry and during winter when there is no melt, several validation studies (e.g., Comiso et al., 2003; Cavalieri et al., 2006; Andersen et al., 2007) have shown that concentration accuracy is within 5%. However, in less optimal regions (as discussed above) concentration biases may be 20% or more (Steffen et al., 1992; Meier, 2005).

Another limitation is low spatial resolution with gridded products at 25 km for much of the record, though more recent sensors and algorithms can provide 12 or 6 km resolution. This limits the precision at which the ice edge location can be estimated. While the low resolution is not a major limitation for large-scale climate studies, it severely limits the utility of passive microwave data for operational ice analyses.

SAR data is most useful for observing small-scale sea ice processes, such as lead and polynya formation, ridging, and estimating floe size (e.g., Kwok, 2002). The primary limitation of SAR is cost/accessibility and coverage. Another limitation is the complexity of the backscatter signal and the general need for manual interpretation. SAR is extremely valuable input into operational ice analyses.

Clouds significantly limit visible and infrared imagery. Visible data is only feasible during summer and infrared is most useful during winter because summer melt yields a nearly isothermal surface. Still, such data provide higher resolution than passive microwave, easier interpretation than SAR, and provide information on important flux parameters (e.g., albedo, temperature).

Sea ice thickness estimates from satellite has been limited because of the lack of altimeter coverage. Starting with the NASA ICESat mission in 2003, near-complete polar coverage was finally attained. However, due to limitations of the lasers, ICESat operations were limited to only two month-long campaigns per year. And ICESat failed before the launch of the radar altimeter on the ESA CryoSat-2 satellite. Airborne measurements from the NASA IceBridge project fill in some gaps and provide an intercalibration bridge between the instruments. Beyond the limited coverage of sea ice by sensors, there are considerable difficulty in obtaining thickness observations from the raw data due to the precision needed for the freeboard measurement to obtain a reasonable total thickness accuracy, and because of uncertainties in ice density, altimeter penetration depth (particularly for radar), and especially snow properties (especially depth and density). Nonetheless, thickness estimates have been produced from ICESat-2 (e.g., Kwok et al., 2009) and preliminary fields from CryoSat-2 (Laxon et al., 2013). Passive microwave data has from the new ESA SMOS sensor has shown the capability to obtain thickness of thin ice up to ~50 cm (Kaleschke et al., 2012) and visible/infrared imagery can also be used to calculate thickness up to a threshold level in concert with a radiative transfer model (Wang et al., 2010).

Sea ice motion is generally derived via cross-correlation feature matching algorithms (e.g., Emery et al., 1997). Thus any input imagery can be employed. Accuracy depends mostly on spatial resolution, with higher resolution providing greater accuracy. However, even though of lower resolution, passive microwave imagery has been the primary source of motion data because of its all-sky capabilities and complete daily coverage.

The future of satellite observations for sea ice is mixed. While passive microwave imagers have been the workhorses for sea ice products and the climate record produce from them is one of the most important from satellites, the long-term future is uncertain beyond 2020, perhaps sooner if sensors fail before planned lifetimes. At the moment, only ESA has preliminary plans for an operational passive microwave beyond 2020 and there could be a gap with current sensors. Overlaps between sensors are extremely important to be able to accurately intercalibrate and assure consistency over the time series and accurate trend estimates. SAR data has been primarily limited by cost because of the use of a commercial model. Future SAR missions with access to researchers and operational analysts are critical. There has already been a gap in thickness estimates from satellite altimeters and another gap is likely unless CryoSat-2 continues to operate beyond is nominal mission until the launch of ICESat-2 in 2017. Visible/infrared is likely more stable overall due to their importance of polar orbiting sensors for weather models. However, a gap is possible in U.S. capabilities if the current MODIS and VIIRS sensors fail before a replacement is launched.

References:

Andersen, S., R. Tonboe, L. Kaleschke, G. Heygster, and L.T. Pedersen, 2007: Intercomparison of passive microwave sea ice concentration retrievals over the high-concentration Arctic sea ice. *J. Geophys. Res.*, **112**, C08004, doi:10.1029/2006JC003543.

Cavalieri, D. J., T. Markus, D. K. Hall, A. J. Gasiewski, M. Klein, and A. Ivanoff, 2006: Assessment of EOS Aqua AMSR-E Arctic sea ice concentrations using Landsat-7 and airborne microwave imagery. *IEEE Trans. Geosci. Rem. Sens.*, **44**, 3057–3069, doi:10.1109/TGRS.2006.878445.

Comiso, J. C., D. J. Cavalieri, and T. Markus, 2003: Sea ice concentration, ice temperature, and snow depth using AMSR-E data. *IEEE Trans. Geosci. Rem. Sens.*, **41**, 243–252, doi:10.1109/TGRS.2002.808317.

Emery, W. J., C. W. Fowler, and J. A. Maslanik, 1997: Satellite-derived maps of Arctic and Antarctic sea ice motion: 1988 to 1994. *Geophys. Res. Lett.*, **24**, 897–900, doi:10.1029/97GL00755.

Heinrichs, J. F., D. J. Cavalieri, and T. Markus, 2006: Assessment of the AMSR-E Sea Ice-Concentration Product at the Ice Edge Using RADARSAT-1 and MODIS Imagery. *IEEE*

Trans. Geosci. Rem. Sens., **44**, 3070–3080, doi:10.1109/TGRS.2006.880622.

Hollmann, R., and Coauthors, 2013: The ESA Climate Change Initiative: Satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, 94, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Kaleschke, L., X. Tian-Kunze, N. Maaß, M. Mäkynen, and M. Drusch, 2012: Sea ice thickness retrieval from SMOS brightness temperatures during the Arctic freeze-up period. *Geophys. Res. Lett.*, **39**, L05501, doi:10.1029/2012GL050916, 2012.

Kern, S., and Coauthors, 2014:. About uncertainties in sea ice thickness retrieval from satellite radar altimetry: results from the ESA-CCI Sea Ice ECV Project Round Robin Exercise. *The Cryosphere Disc.*, **8**, 1517–1561, doi:10.5194/tcd-8-1517-2014

Kwok, R., 2002: Sea ice concentration from passive microwave radiometry and openings from SAR ice motion. *Geophys. Res. Lett*, **29**, 1311, doi:10.1029/2002GL014787.

Kwok, R., G. F. Cunningham, M. Wensnahan, I. Rigor, H. J. Zwally, and D. Yi, 2009: Thinning and volume loss of Arctic sea ice: 2003-2008. *J. Geophys. Res. Oceans*, **114**, C07005, doi:10.1029/2009JC005312.

Laxon, S. W., and Coauthors, 2013: CryoSat-2 estimates of Arctic sea ice thickness and volume. *Geophys. Res. Lett.*, **40**, 732–737, doi:10.1002/grl.50193.

Markus, T., and D. J. Cavalieri, 2000: An enhancement of the NASA Team sea ice algorithm. *IEEE Trans. Geosci. Rem. Sens.*, **38**, 1387-1398, doi:10.1109/36.843033.

Meier, W. N., 2005: Comparison of passive microwave ice concentration algorithm retrievals with AVHRR imagery in arctic peripheral seas. *IEEE Trans. Geosci. Rem. Sens.*, **43**, 1324–1337, doi:10.1109/TGRS.2005.846151.

Steffen, K., and Coauthors, 1992. The estimation of geophysical parameters using passive microwave algorithms. In *Microwave Remote Sensing of Sea Ice*, F. D. Carsey, Ed., *AGU Geophysical Monograph 68*, pp. 47–71.

Wang, X., J. R. Key, and Y. Liu, 2010: A thermodynamic model for estimating sea and lake ice thickness with optical satellite data. *J. Geophys. Res. Oceans*, **115**, C12035, doi:10.1029/2009JC005857.

5.4.8 Oceanic Domain – Sub-surface: General

5.4.8.1 GCOS/CEOS Action O28; SS: N/A

Action: Develop projects designed to assemble the *in situ* and satellite data into a composite reference reanalysis dataset, and to sustain projects to assimilate the data into models in ocean reanalysis projects.
Who: Parties' national ocean research programmes and space supported by WCRP.
Time-Frame: Continuous.
Performance Indicator: Project for data assembly launched, availability and scientific use of ocean reanalysis products.
Annual Cost Implications: 1-10M US$ (10% in non-Annex-I Parties).

CEOS will work collaboratively with the WCRP towards the development of ocean climate reanalyses, including all appropriate historical data assimilated into ocean models, to create climate variability and trend analyses, and to support seasonal-interannual to decadal climate prediction. Furthermore, the CEOS Virtual Constellation for Sea Surface Temperature (SST-VC), which serves as the formal link between the Group for High-Resolution Sea Surface Temperature (GHRSST) and the broader CEOS community, will support efforts to develop analyses and reliable datasets and products of climate variability and trends.

The complete CEOS response to this action is under development.

2015 Update

The CEOS-CGMS Working Group on Climate has endorsed the observations for model intercomparison (Obs4MIPS) to facilitate the use and intercomparison of space-based ECVs with model and re-analysis data sets.

5.4.9 Oceanic Domain – Scientific and Technological Challenges: Global-scale Observation Capabilities

5.4.9.1 GCOS/CEOS Action O41; SS N/A

Action: Promote and facilitate research and development (new improved technologies in particular), in support of the global ocean observing system for climate. **Who:** Parties' national ocean research programmes and space agencies, in cooperation with GOOS, GCOS, and WCRP. **Time-Frame:** Continuing. **Performance Indicator:** More cost-effective and efficient methods and networks; strong research efforts related to the observing system; number of additional ECVs feasible for sustained observation; improved utility of ocean climate products. **Annual Cost Implications:** 30-100M US$ (10% in non-Annex-I Parties).

The complete CEOS response to this action is under development.

2015 Update

The CEOS-CGMS Working Group on Climate is supporting the GEO Blue Planet initiative that seeks to bring together all the existing ocean observation programmes within GEO, to add new ones to the GEO portfolio, and to create synergies between them.

5.5 The Land

5.5.1 Introduction

Compared to the oceans, the land has a relatively low heat capacity, resulting in large diurnal and seasonal variations of surface temperature. Land interacts with the atmosphere through transfers of heat, moisture, radiation, greenhouse gases, and momentum at their common interface. These interactions can lead to significant climate feedbacks, *e.g.*, the snow-albedo feedback mechanism, in the short term, and land cover change-biogeophysical and biogeochemical feedbacks in the longer term. Ice sheets covering the land, with their high heat capacities, have response times of hundreds of years or more. The biosphere plays a key role in carbon cycling, evapotranspiration, and land surface albedo. And, human and natural disturbances of the biosphere – fires, droughts, and land clearing – can have important climatic effects.

The land domain ECVs for which satellite observations make a significant contribution are listed in Table 2 of Section 3.

5.5.2 Monitoring of Terrestrial Biodiversity and Habitats at Key Ecosystem Sites

5.5.2.1 GCOS/CEOS Action T5; SS: T.12

Action: Develop an experimental evaporation product from existing networks and satellite observations.
Who: Parties, national services, research groups through GTN-H, the Integrated Global Water Cycle Observations (IGWCO) partners, TOPC, GEWEX Land Flux Panel and WCRP CliC.
Time frame: 2013-2015.
Performance indicator: Availability of a validated global satellite product of total evaporation.
Annual Cost Implications: 1-10M US$ (10% in non-Annex-I Parties).

CEOS Entities:

- **CEOS Agency Leads:** TBD
- **CEOS Agency Contributors**: NASA, NOAA, ESA
- **CEOS Coordination Mechanisms**: TBD

International Coordination Bodies: GTN-H, the Integrated Global Water Cycle Observations (IGWCO) partners, WCRP partners Terrestrial Observations Panel for Climate (TOPC), and core projects, GEWEX Land/Atmosphere System Study Panel (GLASS) and Climate and Cryosphere (CliC)

Associated Organizations: TBD

Specific Deliverable(s):

- Ongoing and recently launched satellite missions will provide the data needed to develop an evaporation product that combines *in situ* and satellite observations. Accurate satellite observations of total-column water vapor will facilitate the establishment of reliable links between humidity changes and changes in precipitation and evaporation.
- SMOS and Aquarius/SAC-D measure soil moisture and sea surface salinities, key variables related to evaporation from land and ocean.
- Satellite observations of lake level and area provide information on lake water volume, which is an integrator of a number of variables including evaporation.

2015 Update

Space Agencies have funded efforts to produce evaporation products from in situ and satellite data through the use of surface energy balance models. These efforts are coordinated by the WCRP GEWEX Data and Assessment Panel.

5.5.3 Lakes

Importance of this ECV
The world's 150 largest lakes contain 95% of the water in all the world's lakes. Most of these large lakes are hydrologically open. The volume of water in lakes reflects both atmospheric (precipitation, evaporation-energy) and hydrological conditions (surface-water recharge, discharge and ground-water tables). Observing lake freeze-up and break-up dates is an important indicator for climate change in boreal and polar regions.

5.5.3.1 GCOS/CEOS Action T8; SS: T.1.1 and T.1.2

Action: Submit weekly/monthly lake level/area data to the International Data Centre; submit weekly/monthly altimeter-derived lake levels by space agencies to HYDROLARE.
Who: National Hydrological Services through WMO CHy, and other institutions and agencies providing and holding data; space agencies; HYDROLARE.
Time-Frame: 90% coverage of available data from GTN-L by 2012.
Performance Indicator: Completeness of database.
Annual Cost Implications: 1-10M US$ (40% in non-Annex-I Parties).

CEOS Entities:
- **CEOS Agency Leads:** CNES
- **CEOS Agency Contributors**: NASA, NOAA, ESA, ISRO, EUMETSAT
- **CEOS Coordination Mechanisms**: TBD

International Coordination Bodies: TBD

Associated Organizations: TBD

Specific Deliverable(s):
- Standardized long-term and near-real time surface water height variations from the historical and current suite of satellite radar altimeters. Data should include target location (central latitude/longitude), type (natural or man-made impoundment such as open/closed/ephemeral lake and reservoir), time of measurement, average height, height error, reference frame, mean radar backscatter coefficient and/or freeze/thaw indicator, correction matrix. The matrix should describe which altimetric range and height corrections have been applied, and their assumed errors.

- Standardized long-term and near real time lake surface extent derived from satellite imaging instruments.

Accuracy, stability, horizontal resolution, and vertical resolution

ECV: Lakes	**GCOS/CEOS Action T8**		
	Property		
		Lake level	Lake area
Accuracy	Target	50 cm	5%
	Planned	10 cm	5%
Stability (%/decade)	Target	10 cm	5
	Planned	TBD	TBD
Horizontal resolution (km)	Target	N/A	0.25
	Planned	TBD	TBD

Key activities and time frames to meet deliverables (2011 – 2015)

- Require a high resolution map showing location of world's lakes.
- Require international consensus and cooperation's on formation and implementation of any global database.
- Requires formation of dedicated team to ingest, assemble and deliver lake level products. Near real time applications will require system automation with some manual oversight.

2015 Update

Lake level was routinely reported by the ENVISAT altimeter until the end of the mission in May 2012. Lake levels are currently reported by the ISRO Satellite with ARgos and ALtiKa (SARAL) mission.

5.5.3.2 GCOS/CEOS Action T10; SS: N/A

Action: Submit weekly surface and sub-surface water temperature, date of freeze-up and date of break-up of lakes in GTN-L to HYDROLARE.
Who: National Hydrological Services and other institutions and agencies holding and providing data; space agencies.
Time-frame: Continuous.
Performance Indicator: Completeness of database
Annual Cost Implications: <1M US$ (40% in non-Annex-I Parties).

CEOS Entities:

- **CEOS Agency Leads:** NASA, ESA
- **CEOS Agency Contributors**: NOAA
- **CEOS Coordination Mechanisms**: TBD

International Coordination Bodies: Global Lake Temperature Collaboration (GLTC), GHRSST

Associated Organizations: TBD

Specific Deliverable(s):

- Weekly surface water temperatures for 500 largest inland water bodies
- from a model that assimilates satellite observations
- Weekly sub-surface water temperatures for 500 largest inland water bodies
- Dates of freeze-up and break up for large inland water bodies in appropriate climate zones

Accuracy, stability, horizontal resolution, and vertical resolution

ECV: Lakes	**GCOS/CEOS Action T10**			
	Property			
		Surface temperature (weekly)	Assimilation model sub-surface temperature (weekly)	Date of freeze-up
Accuracy	Target	0.1 K	0.2 K	hr
	Planned	0.2 K	2 K	day
Stability (K/decade)	Target	0.05 K/decade	0.05 K/decade	TBD
	Planned	0.1 K/decade	0.1 K/decade	TBD
Horizontal resolution (km)	Target	0.1	1	Whole body
	Planned	1	Whole body	Whole body
Vertical resolution (m)	Target	N/A	1	N/A
	Planned	N/A	1	N/A

Key activities and time frames to meet deliverables (2011 – 2015)

- Automated generation of the surface temperature of the largest 500 inland water bodies from all available satellites with 1 km resolution (AVHRR, Along Track Scanning Radiometer [ATSR], Moderate Resolution Imaging Spectroradiometer [MODIS], VIIRS). Each sensor would provide a set of discrete temperatures
- Single temperature product generated from all products generated weekly
- Single temperature product generated from all other products and models (this would provide temperatures on cloudy days. Retrievals would be daily).

2015 Update

There is no update of this action available.

5.5.4 Soil Moisture

Importance of this ECV

Soil moisture is an important variable in land-atmosphere feedbacks because of its major effect on the partitioning of incoming radiation into latent and sensible heat and on the allocation of precipitation into runoff, subsurface flow, and infiltration. Soil moisture is intimately involved in the feedback between climate and vegetation, since local climate and vegetation both influence soil moisture through evapotranspiration, while soil moisture and climate determine the type of vegetation in a region. Soil moisture estimates can also assist gas flux estimates in permafrost regions. As a climate impact variable, soil moisture affects agricultural and natural vegetation productivity, the likelihood of flash floods, the management of agricultural and city water, and the spread of vector-borne diseases such as Dengue fever and malaria.

5.5.4.1 GCOS/CEOS Action T13; SS: T.11

Action: Develop a record of validated globally-gridded near-surface soil moisture from satellites.
Who: Parties' national services and research programmes, through GEWEX and TOPC in collaboration with space agencies.
Time frame: 2014.
Performance indicator Availability of globally validated soil moisture products from the early satellites until now.
Annual Cost Implications: 1-10M US$ (10% in non-Annex-I Parties).

CEOS Entities:

- **CEOS Agency Leads:** ESA
- **CEOS Agency Contributors**: EUMETSAT, NASA
- **CEOS Coordination Mechanisms**: TBD

International Coordination Bodies: International Soil Moisture Working Group (ISMWG), GEWEX, TOPC, WCRP Data and Assimilation Committee (WDAC)

Associated Organizations: TBD

Specific Deliverable(s):

- 30+ years surface soil moisture data record derived from active (European Remote Sensing Satellite-2 [ERS-2] scatterometer, Metop Advanced Scatterometer [ASCAT]) and passive (Scanning Multichannel Microwave Radiometer [SMMR], TMI, Advanced Microwave Scanning Radiometer – EOS [AMSR-E], Windsat, SSM/I) microwave observations. Unit will be in volumetric soil moisture (m^3m^{-3}) and alternatively in degree of saturation (%). ESA projects Water Cycle Observation Multi-mission Strategy (WACMOS) (http://wacmos.itc.nl/) and ESA's Climate Change Initiative (CCI - the soil moisture project) recently begun in December 2011.

Accuracy, stability, horizontal resolution, and vertical resolution

<table>
<tr><td rowspan="3">ECV: Soil moisture</td><td colspan="2">GCOS/CEOS Action T13</td></tr>
<tr><td colspan="2">Property</td></tr>
<tr><td colspan="2">Soil moisture</td></tr>
<tr><td rowspan="2">Accuracy (m^3m^{-3})</td><td>Target</td><td>0.04</td></tr>
<tr><td>Planned</td><td>0.08, Variable, dependent on land cover</td></tr>
<tr><td rowspan="2">Stability (m^3m^{-3} per year)</td><td>Target</td><td>0.01</td></tr>
<tr><td>Planned</td><td>0.01, Variable, dependent on land cover</td></tr>
<tr><td rowspan="2">Horizontal resolution (km)</td><td>Target</td><td>50</td></tr>
<tr><td>Planned</td><td>100 km, Variable over time</td></tr>
</table>

Key activities and time frames to meet deliverables (2011 – 2015)

- Completion of the ESA project WACMOS (early-mid 2012)
- Climate Change Initiative (CCI) Soil Moisture project (12/2011-11/2014)

2015 Update

- The successful completion of the ESA project WACMOS in 2012 provided the functional design of the CCI SM production system.
- Building upon the work undertaken in WACMOS, in collaboration with ESA's CCI SM project, June 2012 saw the release of the first 30+ year, global, soil moisture project derived from active and passive EO data sets.
- The third data set (product) release of CCI SM v02.1 was made in Sept 2014 providing 35 years of data from 1978 onwards, and is freely available, after registration, via http://www.esa-soilmoisture-cci.org/
- As provided in the recently authored Product Validation and Intercomparison Report (Nov 2014), available from CCI SM web site (Jan 2015), the CCI SM data set has been successfully, independently, validated and compared against in situ, modelled and other satellite datasets.
- A review of the CCI phase 1 SM product in January 2014, using the modified bates maturity index of the CORE-CLIMAX project, resulted in an overall score of 3 (Initial Operations Capacity).
- Since the first product release in 2012 more than 1200 users have registered to date to obtain the product. The product enjoys a global uptake with the majority of users coming from the USA, China and India, and a strong following across the EU, and Australasia. The users focus largely on Climate, Water and Ecosystem issues, although Disaster and Agriculture are also key topics
- Following the successful completion of CCI SM phase 1 in Dec 2014, phase 2 (CCI SM 2) started on 1.1. 2015, running to 31.12.2017 and, in close collaboration with user groups, sees the graceful evolution of the implementation of the production system towards an operational system.
- CEOS WGCV, through the Focus Area on Soil Moisture within the Land Product Validation Subgroup, has taken on a coordination role for the validation and inter-comparison of satellite-derived soil moisture products.

References:

Albergel, C., and Coauthors, 2013: Monitoring multi-decadal satellite earth observation of soil moisture products through land surface reanalyses. *Remote Sens. Environ.*, **138**, 77–89, doi:10.1016/j.rse.2013.07.009.

Albergel, C., and Coauthors, 2013: Skill and global trend analysis of soil moisture from reanalyses and microwave remote sensing. *J. Hydrometeor.*, **14**, 1259–1277, doi:10.1175/JHM-D-12-0161.1.

Atmospheric science: Detecting rainfall from the bottom up. *Nature*, **509**, 262–263. doi:10.1038/509262e.

Barichivich, J., and Coauthors, 2014: Temperature and snow-mediated moisture controls of summer photosynthetic activity in northern terrestrial ecosystems between 1982 and 2011. *Remote Sens.*, **6**, 1390–1431, doi:10.3390/rs6021390.

Barrett, B., I. Nitze, S. Green, and F. Cawkwell, 2014: Assessment of multi-temporal, multi-sensor radar and ancillary spatial data for grasslands monitoring in Ireland using machine learning approaches. *Remote Sens. Environ.*, **152**, 109–124, doi:10.1016/j.rse.2014.05.018.

Bauer-Marschallinger, B., W. A. Dorigo, W. Wagner, and A. I. J. M. van Dijk, 2013: How oceanic oscillation drives soil moisture variations over mainland Australia: An analysis of 32 years of satellite observations. *J. Climate*, **26**, 10159–10173, doi:10.1175/JCLI-D-13-00149.1.

Brocca, L., and Coauthors, 2014:. Soil as a natural rain gauge: Estimating global rainfall from satellite soil moisture data. *J. Geophys. Res. Atmos.*, **119**, 5128–5141, doi:10.1002/2014JD021489.

Chen, T., R. A. M. de Jeu, Y. Y. Liu, G. R. van der Werf, and A. J. Dolman, 2014: Using satellite based soil moisture to quantify the water driven variability in NDVI: A case study over mainland Australia. *Remote Sens. Environ.*, **140**, 330–338, doi:10.1016/j.rse.2013.08.022.

De Jeu, R. A. M., W. A. Dorigo, R. M. Parinussa, W. Wagner, and D. Chung, 2012: Soil moisture [in “State of the Climate in 2011”]. *Bull. Amer. Meteor. Soc.*, **93**(7), S30–S34.

De Jeu, R. A. M., T. R. H. Holmes, R. M. Parinussa, and M. Owe, 2014: A spatially coherent global soil moisture product with improved temporal resolution. *J. Hydrol.*, **516**, 284–296, doi:10.1016/j.jhydrol.2014.02.015.

Diodato, N., L. Brocca, G. Bellocchi, F. Fiorillo, and F. M. Guadagno, 2014: Complexity-reduction modelling for assessing the macro-scale patterns of historical soil moisture in the Euro-Mediterranean region. *Hydrolog. Processes*, **28**, 3752–3760, doi:10.1002/hyp.9925.

Dorigo, W. A., and Coauthors, 2014: Evaluation of the ESA CCI soil moisture product using ground-based observations. *Remote Sens. Environ.*, **162**, 380–395, doi:10.1016/j.rse.2014.07.023.

Dorigo, W., R. de Jeu, D. Chung, R. Parinussa, Y. Liu, W. Wagner, and D. Fernández-Prieto, 2012: Evaluating global trends (1988-2010) in harmonized multi-satellite surface soil moisture. *Geophys. Res. Lett.*, **39**, L18405, doi:10.1029/2012GL052988.

Dorigo, W., and Coauthors, 2014: Soil moisture [in “State of the Climate in 2013”]. *Bull. Amer. Meteor. Soc.*, **95**(7), S25–S26.

Griesfeller, A., and Coauthors, 2013: Evaluation of SMOS and ASCAT soil moisture products over Norway using ground-based in situ observations. *EGU General Assembly 2013*. Retrieved from http://adsabs.harvard.edu/abs/2013EGUGA..15.3897G

Hirschi, M., B. Mueller, W. Dorigo, and S. I. Seneviratne, 2014: Using remotely sensed soil moisture for land–atmosphere coupling diagnostics: The role of surface vs. root-zone soil moisture variability. *Remote Sens. Environ.*, **154**, 246–252, doi:10.1016/j.rse.2014.08.030.

Hollmann, R., and Coauthors, 2013: The ESA Climate Change Initiative: Satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, **94**, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Holmes, T. R. H., W. T. Crow, and R. A. M. de Jeu, 2014: Leveraging microwave polarization information for the calibration of a land data assimilation system. *Geophys. Res. Lett.*, 41, 8879–8886, doi:10.1002/2014GL061991.

Kim, S., Y. Y. Liu, F M. Johnson, R. M. Parinussa, and A. Sharma, 2015: A global comparison of alternate AMSR2 soil moisture products: Why do they differ? *Remote Sens. Environ.*, **161**, 43–62, doi:10.1016/j.rse.2015.02.002.

Lahoz, W. A., and G. J. M. De Lannoy, 2014: Closing the gaps in our knowledge of the hydrological cycle over land: Conceptual problems. *Surv. Geophys.*, **35**, 626–666, doi:10.1007/s10712-013-9221-7

Lahoz, W. A., and P. Schneider, 2014: Data assimilation: Making sense of Earth observation. *Frontiers Environ. Sci.*, **2**, 16, doi:10.3389/fenvs.2014.00016.

Liu, Y. Y., and Coauthors, 2012: Trend-preserving blending of passive and active microwave soil moisture retrievals. *Remote Sens. Environ.*, **123**, 280–297, doi:10.1016/j.rse.2012.03.014.

Liu, Y. Y., and Coauthors, 2011: Developing an improved soil moisture dataset by blending passive and active microwave satellite-based retrievals. *Hydrol. Earth Syst. Sci.*, **15**, 425–436, doi:10.5194/hess-15-425-2011.

Liu, Y. Y., A. I. J. M. van Dijk, R. A. M. de Jeu, J. G. Canadell, M. F. McCabe, J. P. Evans, and G. Wang, 2015: Recent reversal in loss of global terrestrial biomass. *Nature Climate Change*, **5**, 470–474, doi:10.1038/nclimate2581.

Loew, A., T. Stacke, W. Dorigo, R. de Jeu, and S. Hagemann, 2013: Potential and limitations of multidecadal satellite soil moisture observations for selected climate model evaluation studies. *Hydrol. Earth Syst. Sci.*, **17**, 3523–3542, doi:10.5194/hess-17-3523-2013.

Miralles, D. G., and Coauthors, 2013: El Niño–La Niña cycle and recent trends in continental evaporation. *Nature Climate Change*, **4**, 122–126, doi:10.1038/nclimate2068.

Muñoz, A. A., and Coauthors, 2013: Patterns and drivers of *Araucaria araucana* forest growth along a biophysical gradient in the northern Patagonian Andes: Linking tree rings with satellite observations of soil moisture. *Austral Ecol.*, **39**, 158–169, doi:10.1111/aec.12054.

Parinussa, R. M., 2013: Uncertainty characterisation in remotely sensed soil moisture. Ph.D. thesis, VU University Amsterdam. Retrieved from http://dare.ubvu.vu.nl/bitstream/handle/1871/41480/dissertation.pdf?sequence=1.

Parinussa, R. M., T. R. H. Holmes, and R. A. M. de Jeu, 2012: Soil moisture retrievals from the WindSat spaceborne polarimetric microwave radiometer. *IEEE Trans. Geosci. Remote Sens.*, **50**, 2683–2694, doi:10.1109/TGRS.2011.2174643.

Parinussa, R. M. and Coauthors, 2013: Soil moisture [in "State of the Climate in 2012"]. *Bull. Amer. Meteor. Soc.*, **94**(8), S24–S25.

Parinussa, R. M., T. R. H. Holmes, N. Wanders, W. A. Dorigo, and R. A. M. de Jeu, 2014: A preliminary study towards consistent soil moisture from AMSR2. *J. Hydrometeor.*, **16**, 934–947, doi:10.1175/JHM-D-13-0200.1.

Parinussa, R. M., and Coauthors, 2014: Global surface soil moisture from the Microwave Radiation Imager onboard the Fengyun-3B satellite. *Int. J. Remote Sens.*, **35**, 7007–7029, doi:10.1080/01431161.2014.960622.

Parinussa, R. M., M. T. Yilmaz, M. C. Anderson, C. R. Hain, and R. A. M. de Jeu, 2013: An intercomparison of remotely sensed soil moisture products at various spatial scales over the Iberian Peninsula. *Hydrolog. Proc.*, 28, 4865–4876, doi:10.1002/hyp.9975.

Szczypta, C., J.-C. Calvet, F. Maignan, W. Dorigo, F. Baret, and P. Ciais, 2014: Suitability of modelled and remotely sensed essential climate variables for monitoring Euro-Mediterranean droughts. *Geosci. Model Develop.*, **7**, 931–946. doi:10.5194/gmd-7-931-2014.

Taylor, C. M., R. A. M. de Jeu, F. Guichard, P. P. Harris, and W. A. Dorigo, 2012: Afternoon rain more likely over drier soils. *Nature*, **489**, 423–426, doi:10.1038/nature11377.

Tramblay, Y., E. Amoussou, W. Dorigo, and G. Mahé, 2014: Flood risk under future climate in data sparse regions: Linking extreme value models and flood generating processes. *J. Hydrol.*, **519**, 549–558, doi:10.1016/j.jhydrol.2014.07.052.

Wagner, W., W. Dorigo, R. de Jeu, D. Fernandez, J. Benveniste, E. Haas, and M. Ertl, 2012: Fusion of active and passive microwave observations to create an essential climate variable data record on soil moisture. *ISPRS Ann. Photogram. Remote Sens. Spatial Info. Sci.*, **I-7**, 315–321, doi:10.5194/isprsannals-I-7-315-2012.

Wagner, W., C. Paulik, and W. Dorigo, 2012: The use of Earth observation satellites for soil moisture monitoring [in WMO statement on the status of the global climate in 2012]. WMO-No. 1108.

5.5.4.2 GCOS/CEOS Action T14; SS: T.11

Action: Develop Global Terrestrial Network for Soil Moisture (GTN-SM).
Who: Parties' national services and research programmes, through IGWCO, GEWEX and TOPC in collaboration with space agencies.
Time frame: 2014.
Performance indicator: Fully functional GTN-SM with a set of *in situ* observations (possibly collocated with reference network, cf. T3), with standard measurement protocol and data quality and archiving procedures.
Annual Cost Implications: 1-10M US$ (40% in non-Annex-I Parties).

CEOS Entities:

- **CEOS Agency Leads:** ESA
- **CEOS Agency Contributors**: TBD
- **CEOS Coordination Mechanisms**: TBD

International Coordination Bodies: GEWEX, ISMWG

Associated Organizations: TBD

Specific Deliverable(s):

- International Soil Moisture Network (ISMN) at http://www.ipf.tuwien.ac.at/insitu/

Accuracy, stability, horizontal resolution, and vertical resolution

ECV: Soil moisture	GCOS/CEOS Action T14	
	Property	
	Soil moisture	
Accuracy (m^3m^{-3})	Target	0.04
	Planned	TBD
Stability (m^3m^{-3} per year)	Target	0.01
	Planned	TBD
Horizontal resolution (km)	Target	50
	Planned	TBD
Vertical resolution	Target	TBD
	Planned	Sensors at depths of: 5, 10,20, and 50 Cm

Key activities and time frames to meet deliverables (2011 – 2015)

- ISMN has been set up at http://www.ipf.tuwien.ac.at/insitu/ and runs very successfully
- Initial data quality and archiving procedures have been set up
- Standard measurement protocol still needs to be developed and agreed upon

2015 Update:

- ISMN was set up in 2009 and has been running successfully since then
- Currently, almost 50 networks participate, providing more than 7000 soil moisture data sets from almost 2000 sites worldwide
- The ISMN has been migrated to https://ismn.geo.tuwien.ac.at/
- Data archiving and quality control procedures are mature and fully automated
- The ISMN has been integrated in the Global Terrestrial Network – Hydrology (GTN-H) of the Group on Earth Observations/Integrated Global Water Cycle Observations (GEO/IGWCO) theme in June 2013
- Funding for operations have been provided by ESA and may e xtend into 2018. After this date the funding situation is unclear. To keep ISMN operational in a basic form, a minimum of 100 kEUR/year is needed.
- Surveys sent out to data providers and users reveal that both parties are very satisfied and see an urgent need to continue the ISMN.
- Standard measurement protocol still needs to be developed and agreed upon.

5.5.5 Snow Cover

Importance of this ECV

Snow cover is a sensitive indicator of climate change and plays a key role in the climate system. The high albedo of snow (0.8 to 0.9 for fresh snow) compared to snow free surfaces (0.1 to 0.3) leads to an important feedback mechanism. Increasing surface temperatures cause snow to melt, leading to decreased reflection of solar radiation, enhanced heating of the surface, and further amplification of the surface warming. The strength of the feedback depends on the difference between the snow albedo, which is influenced by the depth and age of the snow cover, vegetation height, the amount of incoming solar radiation and cloud cover, and the background albedo, *i.e*., the albedo of the snow-free surface. Snow cover governs freezing and thawing of the ground and affects soil moisture and runoff. Snow cover has major impacts on water resources, agricultural output, natural vegetation growth, business activity, transportation, and tourism. Snow depth and snow-water equivalent also affect permafrost thermal state, soil temperatures and other characteristics of the ground.

5.5.5.1 GCOS/CEOS Action T16; SS: T.2

Action: Obtain integrated analyses of snow cover over both hemispheres.
Who: Space agencies and research agencies in cooperation with WMO GCW and CliC, with advice from TOPC, AOPC and IACS.
Time-Frame: Continuous.
Performance Indicator: Availability of snow-cover products for both hemispheres.
Annual Cost Implications: 1-10M US$ (Mainly by Annex-I Parties).

CEOS Entities:
- **CEOS Agency Leads:** NASA, NOAA
- **CEOS Agency Contributors**: ESA, EUMETSAT
- **CEOS Coordination Mechanisms**: TBD

International Coordination Bodies: WCRP CLiC

Associated Organizations: GlobSnow

Specific Deliverable(s):
- MODIS snow and ice global daily products have been available since 24 February 2000 and are free to download.
- Rutgers Global Snow Lab provides weekly or daily snow maps over Northern Hemisphere lands from 1966 to the present. These are generated from NOAA analyses and are free.
- Daily to multiple-day maps of snow cover (extent, depth and or snow water equivalent) are also generated by several teams using multi-channel microwave data to support operational programs.

Accuracy, stability, horizontal resolution, and vertical resolution

ECV: Snow cover	**GCOS/CEOS Action T16**		
	Property		
		Snow area	Snow water equivalent
Accuracy	Target	5%	10 mm
	Planned	5%	TBD
Stability(/decade)	Target	4%	10 mm
	Planned	5%	TBD
Horizontal resolution (km)	Target	1 100 m in complex terrain	1
	Planned	TBD	TBD

Key activities and time frames to meet deliverables (2011 – 2015)

- Finalize Air force Weather Agency (AFWA)-NASA Snow Algorithm (ANSA) blended snow product if funding permits and make the data available to all users.
- Study the consistency between the MODIS and VIIRS snow-cover data products and establish error bars.
- Ongoing enhancement of Ice Mapping System (IMS) at the U.S. National Snow and Ice Data Center (NSIDC)
- Further integration of satellite (visible and microwave) and surface information

2015 Update

Global 24 km snow cover estimates for the northern hemisphere using the Rutgers method are now operational through the NOAA Climate Data Records program. There are no routine products on snow cover for the southern hemisphere.

The ESA funded *Satellite Snow Product Intercomparison and Evaluation Experiment (SnowPEx)* intercompars and validates hemispheric and global satellite snow products for estimation of temporal trends of the seasonal snow cover and assessing their accuracy. More than 15 snow extent products from optical satellites and snow water equivalent products from passive microwave data are participating in SnowPEx. At the 2nd International Satellite Snow Product Intercomparison Workshop to be held in Boulder, Colo. (USA), from 14-16 September 2015, first intercomparison results will presented and discussed.

5.5.6 Glaciers and Ice Caps

Importance of this ECV
Changes in glaciers and ice caps provide some of the clearest evidence of climate change. Their decline will cause serious impacts on the many societies that are dependent on glacier meltwater.

5.5.6.1 GCOS/CEOS Action T17; SS: T.3.1, T.3.2

Action: Maintain current glacier observing sites and add additional sites and infrastructure in data-sparse regions, including South America, Africa, the Himalayas, and New Zealand; attribute quality levels to long-term mass balance measurements; complete satellite-based glacier inventories in key areas.
Who: Parties' national services and agencies coordinated by GTN-G partners, WGMS, GLIMS, and NSIDC.
Time-Frame: Continuing, new sites by 2015.
Performance Indicator: Completeness of database held at NSIDC from WGMS and GLIMS.
Annual Cost Implications: 10–30M US$ (80% in non-Annex-I Parties).

CEOS Entities:
- **CEOS Agency Leads:** NASA, NOAA, ESA
- **CEOS Agency Contributors**: EUMETSAT, NOAA
- **CEOS Coordination Mechanisms**: TBD

International Coordination Bodies: WCRP CLiC

Associated Organizations: ESA Climate Change Initiative CCI

Specific Deliverable(s):
- 2D vector outlines of glaciers and ice caps (delineating glacier area), supplemented by digital elevation models for drainage divides and topographic parameters
- Elevation change of glaciers and ice caps, from geodetic methods, in regions where outlines are available

Accuracy, stability, horizontal resolution, and vertical resolution

Variable/ Parameter	Horizontal Resolution	Vertical Resolution	Temporal Resolution	Accuracy	Stability
2D vector outlines, delineating glacier	**15 - 30 m**	**N/A**	**Annual (at the end of the ablation**	**better 5 %**	**15 m**
Elevation data	30 - 100 m	1 m	Decadal	better 5 m	1 m

Key activities and time frames to meet deliverables (2011 – 2015)
- The ESA Climate Change Initiative initiated an Glaciers CCI Project to provide an important contribution on mapping glacier and ice-cap areas in key regions, complemented by ice flow and elevation change observations.

2015 Update

Glaciers_cci is providing an important contribution on mapping glacier and ice-cap areas in key regions, complemented by ice flow and elevation change observations. This effort is focussed on completing the databases on global glaciers in coordination with global efforts though WGMS/GLIMS and the Randolph Glacier Inventory.

Glacier area, elevation change and ice flow velocity are derived using a variety of sensors: high resolution optical, altimeters (ICESat, Cryosat) and SAR. The project has developed online tools for processing optical and microwave observations of glacier flow, and for elevation change using DEM differencing.

Glaciers_cci made major contributions in Norway, Greenland, Alaska, Himalaya, Pamir, Tien Shan, South Georgia, the Andes and Svalbard.

See http://www.esa-glaciers-cci.org for additional information.

References:

Allison, I., W. Colgan, M. King, and F. Paul, 2015: Ice sheets, glaciers and sea level. In *Snow and Ice-Related Hazards, Risks, and Disasters*, W. Haeberli and C. Whiteman (Eds.), Elsevier, pp. 714–748.

Bhambri, R., T. Bolch, P. Kawishwar, D.P. Dobhal, D. Srivastava, and B. Pratap, 2013: Heterogeneity in glacier response in the upper Shyok valley, northeast Karakoram. *The Cryosphere*, **7**, 1385–1398, doi:10.5194/tc-7-1385-2013.

Bolch, T., and Coauthors, 2012: The state and fate of Himalayan glaciers. *Science*, **336**, 310–314, doi:10.1126/science.1215828.

Bolch, T., T. Pieczonka, and D.I. Benn, 2011: Multi-decadal mass loss of glaciers in the Everest area (Nepal Himalaya) derived from stereo imagery. *The Cryosphere*, **5**, 349–358, doi:10.5194/tc-5-349-2011.

Bolch, T., L. Sandberg Sørensen, S.B. Simonsen, N. Mölg, H. Machguth, P. Rastner, and F. Paul, 2013: Mass loss of Greenland's glaciers and ice caps 2003-2008 revealed from ICESat laser altimetry data. *Geophys*. *Res*. *Lett*., **40**, 875–881, doi:10.1002/grl.50270.

Debella-Gilo, M., and A. Kääb, 2012a: Locally adaptive template sizes for matching repeat images of Earth surface mass movements. *ISPRS J*. *Photogram*. *Remote Sens*., **69**, 10–28, doi:10.1016/j.isprsjprs.2012.02.002.

Debella-Gilo, M., and A. Kääb, 2012b: Measurement of surface displacement and deformation of mass movements using least squares matching of repeat high resolution satellite and aerial images. *Remote Sens*., **4**, 43–67, doi:10.3390/rs4010043.

Frey, H., and Coauthors, 2013: Ice volume estimates for the Himalaya–Karakoram region: Evaluating different methods. *The Cryosphere Disc*., **7**, 4813–4854, doi:10.5194/tcd-7-4813-2013.

Gardelle, J., E. Berthier, Y. Arnaud, and A. Kääb, 2013: Region-wide glacier mass balances over the Pamir-Karakoram-Himalaya during 1999–2011. *The Cryosphere*, **7**, 1263–1286, doi:10.5194/tc-7-1263-2013.

Gardner, A. S., and Coauthors, 2013: A reconciled estimate of glacier contributions to sea level rise: 2003 to 2009. *Science*, **340**, 852–857, doi:10.1126/science.1234532.

Heid, T., and A. Kääb, 2012a:. Evaluation of existing image matching methods for deriving glacier surface displacements globally from optical satellite imagery. *Remote Sens*. *Environ*., **118**, 339–355, doi:10.1016/j.rse.2011.11.024.

Heid, T., and A. Kääb, 2012b: Repeat optical satellite images reveal widespread and long term decrease in land-terminating glacier speeds. *The Cryosphere*, **6**, 467–478, doi:10.5194/tc-6-467-2012.

Hollmann, R., and Coauthors, 2013: The ESA Climate Change Initiative: Satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, **94**, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Kääb, A., E. Berthier, C. Nuth, J. Gardelle, and Y. Arnaud, 2012: Contrasting patterns of early twenty-first-century glacier mass change in the Himalayas. *Nature*, **488**, 495–498, doi:10.1038/nature11324.

Kargel, J. S., G. J. Leonard, M. P. Bishop, A Kääb, and B. H. Raup, Eds., 2014: *Global Land Ice Measurements from Space*, Springer, 876 pp., doi:10.1007/978-3-540-79818-7.

Leclercq, P. W., A. Weidick, F. Paul, T. Bolch, M. Citterio, and J. Oerlemans, 2012: Brief communication "Historical glacier length changes in West Greenland." *The Cryosphere*, **6**, 1339–1343, doi:10.5194/tc-6-1339-2012.

Marzeion, B., J. G. Cogley, K. Richter, and D. Parkes, 2014: Attribution of global glacier mass loss to anthropogenic and natural causes. *Science*, **345**, 919–921, doi:10.1126/science.1254702.

Neckel, N., J. Kropáček, T. Bolch, and V. Hochschild, 2014: Glacier mass changes on the Tibetan Plateau 2003–2009 derived from ICESat laser altimetry measurements. *Environ. Res. Lett.*, **9**, 014009, doi:10.1088/1748-9326/9/1/014009.

Nuth, C., and A. Kääb, 2011: Co-registration and bias corrections of satellite elevation data sets for quantifying glacier thickness change. *The Cryosphere*, **5**, 271–290, doi:10.5194/tc-5-271-2011.

Nuth, C., and Coauthors, 2013: Decadal changes from a multi-temporal glacier inventory of Svalbard. *The Cryosphere*, **7**, 1603–1621, doi:10.5194/tc-7-1603-2013.

Nuth, C., T. V. Schuler, J. Kohler, B. Altena, and J. O. Hagen, 2012: Estimating the long-term calving flux of Kronebreen, Svalbard from geodetic elevation changes and mass-balance modelling. *J. Glaciol.*. 58, 119–133, doi:10.3189/2012JoG11J036.

Paul, F., 2011: Sea-level rise: Melting glaciers and ice caps. *Nature Geosci.*, **4**, 71–72, doi:10.1038/ngeo1074.

Paul, F., and Coauthors, 2013: On the accuracy of glacier outlines derived from remote-sensing data. *Ann. Glaciol.*, **54**, 171–182 , doi:10.3189/2013AoG63A296.

Paul, F., and Coauthors, 2013: The Glaciers Climate Change Initiative: Algorithms for creating glacier area, elevation change and velocity products. *Remote Sens. Environ.*, **162**, 408–426, doi:10.1016/j.rse.2013.07.043.

Paul, F., T. Bolch, A. Kaab, T. Nagler, A. Shepherd, and T. Strozzi, 2012: Satellite-based glacier monitoring in the ESA project Glaciers_cci. In *2012 IEEE Int. Geosci. Remote Sens. Symp.*, IEEE, pp. 3222–3225, doi:10.1109/IGARSS.2012.6350738.

Paul, F., and N. Mölg, 2014: Hasty retreat of glaciers in northern Patagonia from 1985 to 2011. *J. Glaciol.*, **60**, 1033–1043, doi: 10.3189/2014JoG14J104.

Pellicciotti, F., C. Stephan, E. Miles, S. Herreid, W. Immerzeel, and T. Bolch, 2014: Mass-balance changes of the debris-covered glaciers in the Langtang Himal, Nepal, between 1974 and 1999. *J. Glaciol.*, **61**, 373–386, doi:10.3189/2015JoG13J237.

Pfeffer, W., and Coauthors, 2014: The Randolph Glacier Inventory: A globally complete inventory of glaciers. *J. Glaciol.*, **60**, 537–552, doi:10.3189/2014JoG13J176.

Pieczonka, T., T. Bolch, W. Junfeng, and L. Shiyin, 2013: Heterogeneous mass loss of glaciers in the Aksu-Tarim Catchment (Central Tien Shan) revealed by 1976 KH-9 Hexagon and 2009 SPOT-5 stereo imagery. *Remote Sens. Environ.*, **130**, 233–244, doi:10.1016/j.rse.2012.11.020.

Rastner, P., T. Bolch, N. Mölg, H. Machguth, and F. Paul, 2012: The first complete glacier inventory for the whole of Greenland. *The Cryosphere Disc.*, **6**, 2399–2436, doi:10.5194/tcd-6-2399-2012.

Rastner, P., T. Bolch, C. Notarnicola, and F. Paul, 2013: A comparison of pixel- and object-based glacier classification with optical satellite images. *IEEE J. Sel. Topics Appl. Earth Obs. Remote Sens.*, **7**, 853–862, doi:10.1109/JSTARS.2013.2274668.

5.5.7 Ice Sheets

Importance of this ECV

Because the major ice sheets have a huge heat capacity and mainly transfer heat by conduction, changes in ice volume generally occur on long time scales – millennia. Snow and ice-albedo feedbacks enhance any initial ice melting due to a forced warming, such as anthropogenic greenhouse gases. As land-based ice melts it alters sea level: ice-volume changes have been one of the primary controls on sea-level change during the past 34 M/yr. Recent research indicates that more rapid changes in ice-sheet mass have contributed to relatively abrupt – decadal to centennial time scales – changes in climate and sea level in the past.

5.5.7.1 GCOS/CEOS Action T20; SS: T.4

Action: Ensure continuity of laser, altimetry, and gravity satellite missions adequate to monitor ice masses over decadal timeframes.
Who: Space agencies, in cooperation with WCRP CliC and TOPC.
Time-Frame: New sensors to be launched: 10-30 years.
Performance Indicator: Appropriate follow-on missions agreed.
Annual Cost Implications: 30-100M US$ (Mainly by Annex-I Parties).

Associated Organizations: ESA Climate Change Initiative CCI (esa.cci.int)

ECV: Ice sheets	**GCOS/CEOS Action T20**			
	Property			
		Surface elevation change	Ice velocity	Mass change
Accuracy	Target	0.1 m/yr	10 m/yr	10 km^3/yr
	Planned	TBD	TBD	TBD
Stability (decade)	Target	0.1 m/yr	10 m/yr	10 km^3/yr
	Planned	TBD	TBD	TBD
Horizontal resolution (km)	Target	0.1	1	50
	Planned	TBD	TBD	TBD

CEOS, through its WGClimate, will cooperate with WCRP CliC and TOPC, to ensure continuity of laser, altimetry, and gravity satellite missions adequate to monitor ice masses over decadal timeframes. Current missions include NASA’s Gravity Recovery and Climate Experiment (GRACE), launched in 2002, and ESA’s CryoSat-2, carrying a precise radar altimeter, and launched in 2010. Also, the RADARSAT-1 and -2 satellites, launched by Canada in 1995 and

2007, are still operating; the TerraSAR-X and TanDEM-X satellites, launched by Germany in 2007 and 2010 are still operating; and the Cosmo-Skymed four-satellite constellation launched between 2007 and 2010 is still currently in operation. Planned missions include the Ice, Cloud, and land Elevation Satellite-2 (ICESat-2), scheduled for launch in early 2016. ICESat-2 is the 2nd-generation of the laser altimeter ICESat mission (January 13, 2003 to August 14, 2010). The Gravity Recovery and Climate Experiment (GRACE) follow-on mission is tentatively scheduled for launch as early as 2017. NASA also operates the IceBridge aircraft to compensate for the gap between ICESat and ICESat-2.

The complete CEOS response to this action is under development.

Key activities and time frames to meet deliverables (2011 – 2015)

- The ESA Climate Change Initiative initiated an Ice Sheet CCI Project which consists of two projects covering the Greenland and Antarctic ice sheets respectively.

2015 Update

Ice_sheets_cci consists of two projects covering the Greenland and Antarctic ice sheets respectively. Both projects provide the same set of ECV parameters:

- Surface Elevation Change (1991-2017) over the whole ice sheets from radar altimeters on ERS-1, ERS-2, Envisat, ICESat, Cryosat, AltiKa and Sentinel-3.
- Ice Velocity from ERS-1, ERS-2, Envisat ASAR, Sentinel-1, Radarsat, Palsar and TerraSAR-X (1991-2017)
  - West Antarctic Ice Sheet and Antarctic Peninsula
  - Greenland ice sheet (2014-2017) from Sentinel-1 SAR
  - Main Greenland glaciers (1991-2017)
- Grounding Line Location from multi-sensor InSAR - ERS-1, ERS-2, Envisat, Sentinel-1, Palsar and TerraSAR-X (1991-2017)
- GRACE-derived mass balance (2002-present)
- Calving Front Location for major outlet glaciers from ERS, Envisat, Sentinel-1 and Sentinel-2. (1991-2017)

Consistency with Glaciers_cci is ensured to avoid double-counting of glaciers, and to ensure all areas of ice-loss are covered.

The projects founded, coordinated and participated in the international Ice Sheet Mass Balance Intercomparison Exercise (IMBIE), and the IPCC Coordinating lead author on ice sheets is closely involved as Chair of the projects' Climate Research Groups.

See: http://www.esa-icesheets-cci.org

Annual cost: seems low. ICESat-2 is $700M, NISAR will be $1.2 B, GRACE follow on ~ $300M

For InSAR, please quote the NASA ISRO SAR (NISAR) mission which was recently made official between India and the US, and will be the first InSAR dedicated mission looking at ice sheets.

For future/current missions:

The EU is providing access to Sentinel-1a and 1b (InSAR), which are tremendously useful.

CSA will launch RADARSAT-3 and a RADARSAT constellation (I think R-3 will be part of that).

There is GRACE follow on but also GRACE-2.

Landsat-8 is useful for ice motion (when no cloud).

The EU will launch Sentinel-3 (altimetry).

References:

Hollmann, R., and Coauthors, 2013: The ESA Climate Change Initiative: Satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, **94**, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Levinsen, J. F., and Coauthors, 2013: ESA's Ice Sheets CCI: Validation and inter-comparison of surface elevation changes derived from laser and radar altimetry over Jakobshavn Isbræ, Greenland – Round Robin results. *The Cryosphere Disc.*, **7**, 5433–5460, doi:10.5194/tcd-7-5433-2013.

Shepherd, A., and Coauthors, 2012: A reconciled estimate of ice-sheet mass balance. *Science*, **338**, 1183–1189, doi:10.1126/science.1228102.

5.5.8 Permafrost

Importance of this ECV

Permafrost, or perennially frozen ground, is a critical component of the cryosphere. Permafrost regions occupy approximately 24% of the terrestrial surface of the Northern Hemisphere. The thickness of permafrost ranges from a few meters to many hundreds of meters, depending on the local climate. The presence or absence of permafrost and its stability depends on ground-surface temperature. Permafrost soils are extremely rich in organic carbon. It is estimated that they trap about twice the total amount of carbon currently in the atmosphere. When the soil remains frozen, the carbon is largely inert, but when the permafrost thaws, the decomposition of organic matter through microbial activity increases sharply, releasing large amounts of carbon into the atmosphere as CO_2 and methane, which amplify any greenhouse effects. As the ground melts, it becomes less stable, undermining the structures of buildings, roads, pipelines, airports, and other industrial facilities, and causing them to collapse.

5.5.8.1 GCOS/CEOS Action T23; SS: T.12

Action: Implement operational mapping of seasonal soil freeze/thaw through an international initiative for monitoring seasonally-frozen ground in non-permafrost regions.
Who: Parties, space agencies, national services, and NSIDC, with guidance from International Permafrost Association, the IGOS Cryosphere Theme team, and WMO GCW.
Time-Frame: Complete by 2015.
Performance Indicator: Number and quality of mapping products published.
Annual Cost Implications: 1-10M US$ (10% in non-Annex-I Parties).

CEOS Entities:

- **CEOS Agency Leads:** NASA
- **CEOS Agency Contributors**: ESA, CSA, JAXA
- **CEOS Coordination Mechanisms**: TBD

International Coordination Bodies: International Permafrost Association, WMO Global Cryosphere Watch (GCW)

Associated Organizations: TBD

Specific Deliverable(s):
The deliverable is for operational mapping and monitoring of soil freeze/thaw state dynamics over the global cryosphere, where seasonally frozen temperatures are a major constraint to landscape water mobility and ecosystem processes. This activity would involve satellite active and passive microwave remote sensing retrievals of landscape freeze/thaw status in context with *in situ* station network measurements of air, vegetation and soil temperature profiles; these observations would be combined within a model data assimilation framework for estimating soil freeze/thaw status with robust characterization of classification accuracy and prediction uncertainty. Appropriate data sources for model assimilation-based predictions of soil freeze/thaw processes, include; 1) satellite multi-frequency and H/V polarization active and passive microwave remote sensing records (*e.g.*, NASA Soil Moisture Active-Passive [SMAP], ESA SMOS, JAXA GCOM-W AMSR, U.S. Defense Meteorological Satellite Program [DMSP] SSM/I sensors); 2) satellite thermal IR based land surface "skin" temperatures (*e.g.*, NASA MODIS, Advanced Spaceborne Thermal Emission and Reflection Radiometer [ASTER], Suomi NPP and JPSS VIIRS sensors); 3) global model reanalysis data (*e.g.*, Global Modeling and Assimilation Office [GMAO], Modern-Era Retrospective Analysis for Research and Applications [MERRA], NCAR National Centers for Environmental Prediction-2 [NCEP2], ERA-Interim); 4) *in situ* measurement network observations of surface meteorology and soil properties (*e.g.*, WMO weather stations, FLUXNET tower sites, Circumpolar Active Layer Monitoring [CALM] network sites); 5) other synergistic ancillary datasets including land cover classification, vegetation canopy leaf area, biomass and optical depth, snow cover, soil texture and terrain data.

Accuracy, stability, horizontal resolution, and vertical resolution

ECV: Permafrost	GCOS/CEOS Action T23	
	Property	
	Freeze/thaw state	
Accuracy (mean spatial classification, %)	Target	80 (daily)
	Planned	80 (daily)
	Threshold	70 (3 days)
Stability (%/decade)	Target	3
	Planned	3
	Threshold	5
Horizontal resolution (km)	Target	1
	Planned	3
	Threshold	25
Vertical resolution (cm)	Target	0-100
	Planned	10
	Threshold	5

Key activities and time frames to meet deliverables (2011 – 2015)

Several objectives and milestones can be accomplished to meet near-term product and science deliverables with minimal cost by leveraging existing datasets and other ongoing programs to maximize potential effectiveness and benefit. These activities have high probability for success in developing a comprehensive soil freeze/thaw product with robust accuracy and well quantified uncertainty to meet the above science objectives.

Global satellite freeze-thaw records are now available from SMMR, SSM/I and AMSR-E that provide relatively well documented accuracy at moderate (25-km) spatial scales and daily (AM/PM) temporal fidelity; these records are available through existing public data archives (*e.g*., NSIDC) and can be exploited immediately together in context with available measurement networks and land models (*e.g*., GEOS-5) for production of soil freeze/thaw estimates with sufficient accuracy to meet science requirements for global monitoring and regional climate change assessment. Soil freeze/thaw products can also be developed by establishing empirical relationships between the existing satellite records and currently available *in situ* soil temperature measurement networks; these empirical models are relatively efficient for smaller regions (*e.g*., over individual monitoring sites and sub-regions), but less robust for continuous regional to global scale predictions of soil freeze/thaw dynamics.

Overlapping satellite active and passive microwave records should be evaluated, integrated and exploited for the production of cross-calibrated brightness temperature and backscatter retrievals and enhanced freeze/thaw records, including finer spatial scales and better resolution of individual landscape elements. These data can then be used with available *in situ* measurements and ancillary data using data assimilation techniques for production of contiguous soil freeze/thaw maps with well quantified accuracy and uncertainty. The accuracy of these products should be sufficient to meet most of the above science requirements though product accuracy is expected to be lower in spatially heterogeneous or higher biomass areas where the satellite retrievals are degraded.

New dedicated satellite operational freeze/thaw products will become available following the planned launch of NASA's SMAP satellite in 2014; these products include level 3 freeze/thaw and level 4 model assimilation based soil moisture and temperature profiles. These products will provide enhanced L-band sensitivity to soil processes and relatively fine (~1km) spatial resolution. Other synergistic satellite microwave retrievals from AMSR2 will become available after the initial functional verification and calibration of the instrument are concluded following the successful May 2012 launch of GCOM-W1/Shizuku. These new retrievals and products can be effectively integrated and exploited for production of higher accuracy soil freeze/thaw products through the methods and activities described above. Dedicated calibration and monitoring sites should also be designated, developed, and sustained that are specifically designed to support soil freeze/thaw product calibration and validation. These sites should be representative of the major biomes and climate regimes within the global cryosphere. The operation and support of these sites can be leveraged with suitable satellite mission activities, including SMOS, AMSR2 and SMAP, to coordinate with various agencies and programs to identify, design and support site observations and field campaigns for sensor and product cal/val activities.

2015 Update

Monthly mean maps of freeze/thaw continue to be produced routinely from AMSR data. NASA successfully launched the Soil Moisture Active Passive (SMAP) on 31 January 2015. NASA plans to produce a daily classification of freeze/thaw state for land areas north of 45°N derived from the SMAP high-resolution radar output to 3 km polar and global EASE grids.

5.5.9 Albedo

Importance of this ECV

The albedo of the Earth's surface is the fraction of solar radiation it reflects and thus controls the heating of the Earth's continents (and oceans). Albedo is a feedback variable affecting the climate and a sensitive indicator of environmental change. Albedo varies in space and time as a result of both natural processes (*e.g*., surface and vegetation types, snowcover, vegetation density and health, and fires) and human activities (*e.g*., forestry, agriculture, and fires). Climate change alters snow and land cover, which affects surface albedos, leading to feedbacks that amplify or diminish the original change.

5.5.9.1 GCOS/CEOS Action T24; SS: T.5

Action: Obtain, archive, and make available *in situ* calibration/validation measurements and collocated albedo products from all space agencies generating such products; promote benchmarking activities to assess the quality and reliability of albedo products.
Who: Space agencies in cooperation with CEOS WGCV.
Time-Frame: Full benchmarking/intercomparison by 2012.
Performance Indicator: Publication of inter-comparison/validation reports.
Annual Cost Implications: 1-10M US$ (20% in non-Annex-I Parties).

CEOS Entities:

- **CEOS Agency Leads:** ESA, NASA
- **CEOS Agency Contributors**: NOAA, EUMETSAT
- **CEOS Coordination Mechanisms**: WGCV

International Coordination Bodies: ISMWG, GEWEX, TOPC, WDAC

Associated Organizations: TBD

Data Contributions:
Satellite-inferred land surface albedo products:

AVHRR, CERES, GEOLAND, GLOBALBEDO, LANDSAT, Meteosat First Generation (MFG), Multiangle Imaging SpectroRadiometer (MISR), MODIS, MSG, POLDER, VIIRS

In situ network data:

Aerosol Robotic Network (AERONET), AMERIFLUX, Baseline Surface Radiation Network (BSRN), CARBOEUROPE, FLUXNET, GAW (Global Atmosphere Watch), ILTER, NEON.

Specific Deliverable(s):

The provision of deliverables is carried out by the Land Product Validation Subgroup (LPV) of CEOS WGCV. As user and access tool the CEOS Cal/Val portal provided by ESA is key element for this action (see http://calvalportal.ceos.org/).

Deliverable 1: Land surface albedo validation protocol
Deliverable 1 is a protocol for satellite albedo validation and intercomparison. It addresses definitions, operational products, description of *in situ* data, strategy for validation (with *in situ* data) and intercomparison (between satellite products) of global products (spatial, temporal, spectral considerations), as well as output metrics to describe data quality.

Existing operational satellite products differ in data input, processing algorithm, and output quantity, with major differences in geometrical configuration (view-sun angle geometry), spatial, temporal, and spectral resolution.

Deliverable 1, the albedo validation protocol, will address definitions of albedo quantities, operational satellite and *in situ* albedo data. Based on the product description, the protocol specifies physical quantities and spatial, temporal and spectral resolutions recommended for validation and intercomparison.

Direct validation of satellite data requires *in situ* measurements. The Baseline Surface Radiation Network (BSRN) data set typifies tower-based albedometer measurements of high radiometric quality. However tower-based measurements cover a footprint that is considerably smaller than the spatial point spread function of a satellite pixel. The protocol therefore addresses a methodology to test the area covered by *in situ* observations for its representativeness at the satellite pixel resolution, as well as temporal selection and averaging of *in situ* data.

The development of a surface albedo validation and intercomparison protocol is planned as activity of the surface radiation focus area of CEOS WGCV LPV, led by G. Schaepman-Strub, C. Schaaf and M. Roman. A draft was compiled in early 2012 and distributed to the LPV surface radiation focus group and all members listed above. A finalized land surface albedo validation protocol is expected by fourth quarter calendar year 2012.

Deliverable 2: Validation and intercomparison algorithm
Based on Deliverable 1 (albedo validation protocol), the OLIVE tool of the CEOS CalVal portal is programmed to comply with the defined statistical design (accuracy measures, temporal and spatial resolution) and format of archived BSRN (Deliverable 2) and satellite data (Deliverable 3). Narrow to broadband conversion is implemented within On-line Interactive Validation Exercise (OLIVE) for sensors restricted to narrowband products.

Deliverable 3: Satellite albedo products
Selection of products: broadband and spectral black-sky (Directional-Hemispherical Reflectance [DHR]) and white-sky albedo (BiHemispherical Reflectance [BHR]), quality flags (Bidirectional Reflectance Distribution Function [BRDF] inversion, backup retrieval, gap-filled etc.), and period of validation. Re-projection of satellite data is performed within Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC).

Deliverable 4: Archived *in situ* network data
Deliverable 4 contains existing *in situ* measurements (Table 1) required for T24 processed to comply with requirements for validation of satellite-inferred albedo products. Highest priority is given to the Baseline Surface Radiation Network (BSRN) data set as a ‘golden standard’ due to its high radiometric quality. Additional network data as listed above will be considered depending on the data quality and site representativeness.

The representativeness of each BSRN site for the spatial resolution of different satellite products will be tested. The representativeness test, based on variograms for leaf-on and leaf-off conditions, was performed for MODIS albedo product resolution (500m), but needs adaptation for the spatial resolutions of all albedo products participating in the validation.

Temporal resolution and coverage of *in situ* data (*e.g*., BSRN, AERONET, FLUXNET) are defined and metadata (*e.g*., cloud cover) generated. Metadata is required as selection criteria for specific atmospheric conditions, such as clear-sky or 100% cloud cover when validating corresponding satellite albedo quantities. A selection of *in situ* network sites and corresponding albedo data and metadata are archived in appropriate temporal resolution and coverage within the CEOS CalVal portal (http://calvalportal.ceos.org) or ORNL DAAC.

T24-Deliverable 5: Satellite product intercomparison results

Based on T24 Deliverables 3 and 4, the intercomparison is performed for all operational satellite albedo products, and results on product differences and biases provided and published in peer-reviewed literature.

T24-Deliverable 6: Satellite products validated against *in situ* data

Based on T24 Deliverables 2-4, product validation is performed for all operational albedo products, and results on data accuracy and stability provided and published in peer-reviewed literature.

Accuracy, stability, horizontal resolution, and vertical resolution

ECV: Albedo	**GCOS/CEOS Action T24**	
	Property	
	Albedo	
Accuracy (%)	Target	max(5%; 0.0025)
	Planned	5
Stability (%/decade)	Target	max(1%; 0.0001)
	Planned	1
Horizontal resolution (km)	Target	1
	Planned	1

Key activities and time frames to meet deliverables (2011 – 2015)

- 10.2012: Deliverable 1: Land surface albedo validation protocol
- 03.2013: Deliverable 2: Validation and intercomparison algorithm
- 09.2013: Deliverable 3: Satellite albedo products
- 09.2013: Deliverable 4: Archived *in situ* network data
- 03.2014: Deliverable 5: Satellite product intercomparison results
- 06.2014: Deliverable 6: Satellite products validated against *in situ* data
- 12.2014: Intercomparison and validation results published in peer-reviewed literature

2015 Update

Sensor-specific validation efforts continued during 2011-2015. Due to a lack of dedicated funding, the planned activities for intercomparison and validation across albedo products and the publication of fiducial reference data set based on in-situ networks are delayed. The Land Product Validation Subgroup of CEOS WGCV has updated and published validation and intercomparison information at the end of 2014 available on the Land Product Validation web site http://lpvs.gsfc.nasa.gov/. The validation and intercomparison protocol is under development.

5.5.9.2 GCOS/CEOS Action T25; SS: T.5

Action: Implement globally coordinated and linked data processing to retrieve land surface albedo from a range of sensors on a daily and global basis using both archived and current Earth Observation systems.
Who: Space agencies, through the CGMS and WMO Space Programme.
Time-Frame: Reprocess archived data by 2012, then generate continuously.
Performance Indicator: Completeness of archive.
Annual Cost Implications: 1-10M US$ (Mainly by Annex-I Parties)

CEOS, through its WGClimate, and working with the CGMS and WMO Space Programme, will coordinate a global effort to construct land surface albedo datasets from archived and current satellite observations. The WMO Space Programme‘s SCOPE-CM has already established a project on land surface albedo:

Surface albedo, clouds and aerosols from geostationary satellite Imagers (Geo).

- Collaborators: EUMETSAT, JMA, and NOAA

SCOPE-CM will build on this start with the goal of adding polar orbiting data and developing an integrated LEO-GEO land surface albedo dataset.

Accuracy, stability, horizontal resolution, and vertical resolution

ECV: Albedo	**GCOS/CEOS Action T24**	
	Property	
	Albedo	
Accuracy (%)	Target	max(5%; 0.0025)
	Planned	TBD
Stability (%/decade)	Target	max(1%; 0.0001)
	Planned	TBD
Horizontal resolution (km)	Target	1
	Planned	TBD

The complete CEOS response to this action is under development.

2015 Update

Two SCOPE-CM projects are ongoing, SCM-02 (Surface albedo LEO) and SCM-03 (Surface albedo GEO) with the aim of evaluating and producing Climate Data Records (CDR) for surface albedo.

a) Surface albedo CDR from Geostationary satellites (SCM-03)

Land surface albedo is a key forcing parameter for the climate system controlling the radiative energy budget. It is the Global Climate Observing System (GCOS) terrestrial Essential Climate Variable (ECV) product T.5 that is described including product requirements in GCOS-154, thus, its monitoring is of primary importance for an understanding of the climate system. Its value changes in space and time, depending on both natural processes (vegetation growth, rain and snowfall and snow melting, wildfires, etc.) and human activities (forestation and deforestation, harvesting crops, anthropogenic fires, etc.). Observations acquired by geostationary satellites have the advantages of offering both a long-term dataset and an angular sampling of the surface as well as providing diurnal sampling of key parameters influencing the retrieval such as cloud cover and aerosol load. The project objective is the generation of a land surface albedo Climate Data Record (CDR) covering the Earth surface seen by geostationary satellites (Polar Regions are not included) for a time window of approximately 30 years. The project aims at a product that includes Level 2 (at the native instrument resolution) and Level 3 (at coarse resolution between 0.25 and 1.0 degree) surface albedo data records to be utilized in climate science and climate services.

Phase 1 (2008-2012)

The SCOPE-CM Phase 1 focused on the establishment of a coordinated network of space agencies and organizations. The main task during this phase is the creation of interagency partnerships and the establishment of the network, for which five pilot projects have been started. During this phase the involved agencies have demonstrated that the current approach is feasible. The involved scientists have all the necessary skills to continue the work including updates to the retrieval system. The team spirit during the unfunded activities of phase 1 was demonstrated by a joint publication in the *Bulletin of the American Meteorological Society* (Lattanzio et al. 2013). During this phase a first processing of the data archives in EUMETSAT, JMA and NOAA has been performed to check the feasibility of such a federated activity.

Phase 2 (2012-2018)

The SCOPE-CM Implementation Plan (SCOPE-CM 2014) was revisited in 2012 and the Land surface albedo from geostationary satellites (LAGS) project has been accepted in 2014. The first objectives are the quality improvement, in particular in terms of residual cloud contamination removal, and a homogenization of the ancillary input information (calibration and NWP data) among the 3 agencies. The need to tackle these issues was a clear outcome of the first phase. The next Level 2 reprocessing campaign is foreseen for 2016. Following the success of such an activity a near-global Level 3 product will be generated and distributed. The project team is confident that the resulting CDR will contribute to climate studies answering questions such as on monsoon decadal scale variability. It will further contribute to the evaluation of quality of climate model simulations by entering the Obs4MIPs initiative and to direct estimates of global surface energy budget.

b) Surface albedo CDR from polar-orbiting satellites (SCM-02)

The geostationary efforts are being augmented by a second SCOPE-CM effort, SCM-02, with contributions by the Finnish Meteorological Institute (FMI), University of Massachusetts (Boston), and EUMETSAT. The aim of this pilot project is to derive a roadmap for estimation of surface albedo using data from several satellite intruments thus benefitting from increased temporal sampling. This method is demonstrated using AVHRR and MODIS images. The quality aims at the GCOS requirements (http://www.scope-cm.org/projects/scm-02/).

Lattanzio A., J. Schulz, J. Matthews, A. Okuyama, B. Theodore, J. J. Bates, K. R. Knapp, Y. Kosaka, and L. Schüller, 2013: Land surface albedo from geostationary satellites: A multi-agency collaboration within SCOPE-CM. *Bull. Amer. Meteor. Soc.*, **94**, 205–214, doi:10.1175/BAMS-D-11-00230.1.

SCOPE-CM, 2014: http://www.scope-cm.org/wpcms/wp-content/uploads/2014/01/SCOPE-CM_Phase-2-Implementation-Plan.pdf

5.5.10 Land Cover

Importance of this ECV

Land cover describes the distribution of natural and agricultural vegetation types, and the human use of the land for living space and infrastructure. Land cover affects the services provided to human society (*e.g.*, food, fibre, shelter, etc.). Natural vegetation distributions are governed by climatic factors – primarily sunshine, rainfall, and temperature – and changes in vegetation provide a way to monitor climate change. But land cover also influences the climate. Key links between changes in land cover and climate include the exchange of greenhouse gases (such as water vapor, carbon dioxide, methane, and nitrous oxide) between the land surface and the atmosphere, the radiation (both solar – through surface albedo changes – and long-wave – through emissivity changes) balance of the land surface, the exchange of sensible heat between the land surface and the atmosphere, and the roughness of the land surface and its uptake of momentum from the atmosphere. Because of these strong links, changes in land use and land cover can be important contributors to climate change and variability. Human activities such as deforestation and slash/burn agricultural practices modify land cover and introduce an additional anthropogenic forcing to the climate system.

5.5.10.1 GCOS/CEOS Action T27; SS: T.6.1 (Moderate-resolution maps of land-cover type) and T.6.2 (High-resolution maps of land-cover type)

Action: Generate annual products documenting global land-cover characteristics and dynamics at resolutions between 250 m and 1 km, according to internationally-agreed standards and accompanied by statistical descriptions of their accuracy.
Who: Parties' national services, research institutes and space agencies in collaboration with GLCN and GOFC-GOLD research partners and the Global Forest Observations Initiative (GFOI) R&D and Methods and Guidance components, and the CEOS Space Data Coordination Group for GFOI.
Time-Frame: By 2011, then continuously.
Performance Indicator: Dataset availability.
Annual Cost Implications: 1-10M US$ (20% in non-Annex-I Parties).

CEOS Entities:

- **CEOS Agency Leads:** NASA
- **CEOS Agency Contributors**: ESA, NOAA
- **CEOS Coordination Mechanisms**: TBD (2015 Update: Working Group on Calibration Validation, Land Product Validation Subgroup)

International Coordination Bodies: GOFC-GOLD

Associated Organizations: TBD

Description of the Deliverable(s): Global land cover type maps, produced on a five year cycle, displaying general categories of land cover are required on a five-year cycle to depict the covers and probable land uses across the globe. In addition, fractional land cover components (*e.g.*, trees, herbaceous cover, barren surfaces, water) produced on an annual basis to provide a means to target areas experiencing land cover change and land degradation or improvement.

Accuracy, stability, horizontal resolution, and vertical resolution

ECV: Land cover	**GCOS/CEOS Action T27**		
	Property		
		Land cover type (per class and overall)	Land cover fraction (per pixel)
Accuracy (%)	Target	15 (moderate resolution) 5 (high resolution)	5
	Planned	80	10
Stability (%/decade)	Target	15 (moderate resolution) 5 (high resolution)	5
	Planned	10	10
Horizontal resolution	Target	250 m(moderate resolution) 10-30 m (high resolution)	0.5 input pixels
	Planned	1	1

Key activities and time frames to meet deliverables (2011 – 2015)

- Continuation of MODIS and Medium Resolution Imaging Spectrometer (MERIS) (GlobCover) initiatives (ongoing)
- Implementation of VIIRS Earth cover products (2012)
- Identify strengths and weaknesses between different global land cover products (ongoing)
- The ESA Climate Change Initiative initiated a Land Cover CCI Project.

2015 Update

VIIRS land products are currently under development and initial products may be available in late 2015. See additional information at following the Action, GCOS/CEOS Action T28, SS: T.12.

The Land cover cci project performed optical (MERIS, SPOT-VGT, Proba-V, AVHRR) and SAR (ASAR) image classification, in consultation with international partners, IGBP, GOFC-GOLD, FAO, EEA and JRC, the Land_Cover_cci, to provide:

- Global moderate resolution (300m) land cover maps for epochs: 1990, 2000, 2005, 2010, 2015
- Land cover seasonality characterisation: vegetation greenness, snow and burned area
- Global map of permanent water bodies

Higher resolution land cover mapping is being demonstrated over Africa with Sentinel-2 and Landsat-8 data.

Products are supplemented by a tool for subsetting, re-projecting and re-sampling the products for use in climate modelling.

See: http://www.esa-landcover-cci.org

References :

André, C., C. Ottlé, A. Royer, and F. Maignan, 2015: Land surface temperature retrieval over circumpolar Arctic using SSM/I–SSMIS and MODIS data. *Remote Sens. Environ.*, **162**, 1–10, doi:10.1016/j.rse.2015.01.028.

Bontemps, S., and Coauthors, 2012: Revisiting land cover observation to address the needs of the climate modeling community. *Biogeosciences*, **9**, 2145–2157, doi:10.5194/bg-9-2145-2012.

Gamba, P., and G. Lisini, 2013: Fast and efficient urban extent extraction using ASAR wide swath mode data. *IEEE J. Sel. Topics Appl. Earth Obs. Remote Sens.*, **6**, 2184–2195. doi:10.1109/JSTARS.2012.2235410.

Hollmann, R., and Coauthors, 2013: The ESA Climate Change Initiative: satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, 94, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Ottlé, C., J. Lescure, F. Maignan, B. Poulter, T. Wang, and N. Delbart, 2013: Use of various remote sensing land cover products for PFT mapping over Siberia. *Earth Sys. Sci. Data Disc.*, **6**, 255–296, doi:10.5194/essdd-6-255-2013.

Poulter, B., P. Ciais, E. Hodson, H. Lischke, F. Maignan, S. Plummer, and N. E.Zimmermann, 2011: Plant functional type mapping for earth system models. *Geosci. Model Develop.*, **4**, 993–1010, doi:10.5194/gmd-4-993-2011.

Poulter, B., and Coauthors, 2015: Plant functional type classification for Earth system models: Results from the European Space Agency's Land Cover Climate Change Initiative. *Geosci. Model Develop. Disc.*, **8**, 429–462, doi:10.5194/gmdd-8-429-2015.

Santoro, M., and U. Wegmuller, 2014: Multi-temporal synthetic aperture radar metrics applied to map open water bodies. *IEEE J. Sel. Topics Appl. Earth Obs. Remote Sens.*, **7**, 3225–3238, doi:10.1109/JSTARS.2013.2289301.

5.5.10.2 GCOS/CEOS Action T28; SS: T.12

Action: Generate maps documenting global land cover based on continuous 10–30 m land surface imagery every 5 years, according to internationally-agreed standards and accompanied by statistical descriptions of their accuracy.
Who: Space agencies, in cooperation with GCOS, GTOS, GOFC-GOLD, GLCN, and other members of CEOS.
Time-Frame: First by 2012, then continuously.
Performance Indicator: Availability of operational plans, funding mechanisms, eventually maps.
Annual Cost Implications: 10-30M US$ (20% in non-Annex-I Parties).

CEOS Entities:

- **CEOS Agency Leads:** USGS
- **CEOS Agency Contributors**: NASA
- **CEOS Coordination Mechanisms**: TBD

International Coordination Bodies: GOFC-GOLD

Associated Organizations: China National Geomatics Center for China
ESA Climate Change Initiative CCI (esa.cci.int)

Specific Deliverable(s):
Quantitative land cover components, land cover types: Two forms of land cover are required.

- First, quantitative measurements of the per pixel fraction of major land cover elements (*e.g.*, trees, herbaceous vegetation, barren surfaces, water) are needed on a 1- to 2-year cycle to identify land cover change over time. The fractional coverage measurements represent the continuum of land cover conditions and are more sensitive to detection of both gradual and abrupt change.
- Second, land cover type maps displaying categories of land cover are required on a 5-year cycle to depict the covers and probably land uses across the globe, and to provide context for understanding fractional land cover.

Accuracy, stability, horizontal resolution, and vertical resolution

ECV: Land cover	**GCOS/CEOS Action T28**		
	Property		
		Land cover type (per class and overall)	Land cover fraction (per pixel)
Accuracy (%)	Target	85	5
	Planned	75	8
	Threshold	75	10
Stability (%/decade)	Target	5	5
	Planned	5	5
	Threshold	10	10
Horizontal resolution (m)	Target	30	30
	Planned	30	30
	Threshold	30	30

Key activities and time frames to meet deliverables (2011 – 2015)

- Peer review of product strategy (mid-2012)
- Develop land cover fraction 2010 continental prototype (mid-2012)
- Completion of a global land cover validation data set (late-2013)
- Completion of validated global land cover fractions for 2000-2010 (mid-2013)
- Completion of validated global land cover types for 2010 (early 2014)
- Transition into operational annual monitoring (2013-2014)
- Improve global 30m imagery data set coverage (ongoing)

2015 Update

Key activities:

- Peer review of product strategy (completed)
- Develop land cover fraction 2010 continental prototype (completed 2014)
- Completion of a global land cover validation data set (completed 2015)
- Completion of validated global land cover fractions for 2000-2010 (in progress)
- Completion of validated global land cover types for 2010 (in progress)
- Transition into operational annual monitoring (TBD)
- Improve global 30m imagery data set coverage (TBD)

The USGS, in collaboration with the University of Maryland and other partners, has completed the first Global datasets comprised of per tree cover, percent water, and percent barren land. A validation dataset comprised of 500+ globally distributed sites has been compiled based on high-resolution commercial satellite imagery and from which corresponding percent cover (tree, water, barren) and thematic classifications have been developed. The validation of the circa 2010 datasets is underway and results will be submitted for peer reviewed journal publication.

5.5.11 Fraction of Absorbed Photosynthetically Active Radiation (fAPAR)

Importance of this ECV

The fAPAR is a non-dimensional value that measures the fraction of the incoming solar radiation at the top of the vegetation canopy that contributes to plants' photosynthetic activity, and thus indicates the presence and productivity of live green vegetation. fAPAR varies in space and time due to differences between species and ecosystems, weather and climate processes, and human activities. It is a key variable in the carbon cycle and thus in the assessment of greenhouse gas forcing, providing information on CO_2 uptake. Spatially-detailed descriptions of fAPAR provide information about the strength and location of terrestrial carbon sinks.

5.5.11.1 GCOS/CEOS Action T29; SS: T.7

Action: Establish a calibration/validation network of *in situ* reference sites for FAPAR and LAI
Who: Parties' national and regional research centres, in cooperation with space agencies coordinated by CEOS WGCV, GCOS and GTOS.
Time-Frame: Network operational by 2012.
Performance Indicator: Percentage of sites reporting.
Annual Cost Implications: 1-10M US$ (40% in non-Annex-I Parties).

CEOS Entities:

- **CEOS Agency Leads:** ESA
- **CEOS Agency Contributors**: NASA, CSA, INPE, CSIRO
- **CEOS Coordination Mechanisms**: WGCV (coordination of the deliverables is carried out by the Land Product Validation Subgroup)

International Coordination Bodies: European Environment Agency (EEA) and North American Carbon Programme for *in situ* networks

Associated Organizations: TBD

Specific Deliverable(s):

- Ongoing database of *in situ* measurements of LAI and fAPAR.
- Annual update of global reference database traceable to *in situ* measurements.

Accuracy, stability, horizontal resolution, and vertical resolution

ECV: Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)	**GCOS/CEOS Action T29**	
	Property	
	Fraction of Absorbed Photosynthetically Active Radiation	
Accuracy (%)*	Target	max(10%; 0.05)
	Planned	20
Stability (%)*	Target	max(3%; 0.02)
	Planned	10
Horizontal resolution (km)*	Target	0.25
	Planned	0.25

***Accuracy requirements**
This corresponds to the accuracy of the reference LAI estimate over a 1km x 1km mapping unit. The target reflects the typical precision in destructive sampling approaches that themselves have very high (<5%) accuracy levels. The planned approach reflects the inherent limits currently in using indirect gap fraction or transmission approaches for LAI estimation due to theoretical uncertainty in corrections for clumping and typical uncertainties in corrections for woody matter. The threshold level is rather high but reflects current worst cases error budgets for *in situ* indirect estimates and can still be used with the CEOS LAI and fAPAR validation protocols as long as errors between reference sites are not systematic.

***Stability requirements**
This stability indicates the precision of repeat reference estimates at a site rather than the long term stability of the sites. Target precision corresponds to typical levels of actual variability due to vegetation dynamics and sampling conditions. Planned precision corresponds to reported precision of current indirect measurement instruments. Threshold precision corresponds to approximately the difference in LAI or fAPAR between successive monthly site visits assuming a six-month growing season and annual vegetation.

***Horizontal resolution requirements**
This corresponds to the spatial resolution of reference data provided to users from this system. The target involves local image maps supported by field data, the planned will allow validation of advanced moderate resolution products, and the threshold will allow validation of current and planned global products.

Key activities and time frames to meet deliverables (2011 – 2015)

- Intercomparison study of FLUXNET, Validation of Global Moderate-Resolution LAI Products (VALERI) and Canadian Centre for Remote Sensing (CCRS) protocols over synthetic and *in situ* sites. (2012)
- Produce initial database of *in situ* measurements with local uncertainty estimates (2012)
- Establish systematic updates from contributing networks (2012)
- Produce and make available global reference (2012)
- Identify locations of critical new *in situ* sites (2011-2012)
- Establish new critical *in situ* sites per year (2013-2020)

2015 Update

The Land Product Validation Subgroup of the CEOS WGCV (LPV) has taken on a coordination role to establish fiducial reference data in collaboration with long-term in-situ networks for fAPAR and LAI. The LPV focus area for fAPAR and LAI are in contact with in-situ networks (e.g., NEON, ICOS) to coordinate field sampling protocols. A fAPAR workshop was held in 2014 to discuss details of a fAPAR intercomparison and validation protocol and field instrument set-up and sampling. In 2015, a few sites were instrumented and with calibrated PAR sensors that will allow for the generation of high-quality fAPAR reference data. However, the number of validation sites remains limited (see http://lpvs.gsfc.nasa.gov/Fpar_home.html).

Work on the generation of LAI in-situ reference data has been ongoing. A compiled reference data set has been extended recently for crop- and grassland sites in the framework of the EU Framework Programme 7 project ImagineS (http://fp7-imagines.eu) . It is planned to make these data available through the PLIVE platform.

5.5.12 Leaf Area Index (LAI)

Importance of this ECV
The LAI of a plant canopy measures of the amount of live green leaf material present. It is defined as one half the total green leaf area per unit ground surface area. It partly controls important mass and energy exchange processes such as radiation and rain interception, as well as photosynthesis and respiration, which couple vegetation to the climate system. Many climate models rely on it to parameterize the vegetation cover, or its interactions with the atmosphere. For instance, evapotranspiration and carbon fluxes between the biosphere and the atmosphere are routinely expressed in terms of the LAI of the canopy. It is affected by and influences climate and is thus a response as well as feedback variable.

5.5.12.1 GCOS/CEOS Action T30; SS: T.7

Action: Evaluate the various LAI satellite products and benchmark them against *in situ* measurements to arrive at an agreed operational product.
Who: Parties' national and regional research centres, in cooperation with space agencies and CEOS WGCV, TOPC, and GTOS.
Time-Frame: Benchmark by 2012.
Performance Indicator: Agreement on operational product.
Annual Cost Implications: 1-10M US$ (10% in non-Annex-I Parties).

CEOS Entities:

- **CEOS Agency Leads:** ESA (hosting the CEOS CAL/VAL portal and OLIVE validation platform)
- **CEOS Agency Contributors**: NASA, CSA
- **CEOS Coordination Mechanisms**: WGCV (coordination of the deliverables is carried out by the Land Product Validation Subgroup)

International Coordination Bodies: GTOS

Associated Organizations: TBD

Specific Deliverable(s):

- System capable of updating and disseminating performance estimates of LAI products on an individual and community basis.
- Community consensus assessment of product performance (publication) at a minimum of 5-year intervals.

- Annual updates of product performance (bulletins) in consultation with specific users or producers.

Key activities and time frames to meet deliverables (2011 – 2015)
- Implementing an on-line validation system. (2011)
- Testing system with current global products and reference data (2012)
- Linking on-line system to distributed reference data and product nodes (2012)
- Producing a community consensus validation document (2012 and every 5 years thereafter)
- Issuing annual bulletins on behalf of CEOS/GTOS on product accuracy (2012 onwards)

2015 Update

Completion or significant progress of all planned key activities related to this action has been achieved. The Land Product Validation subgroup of the CEOS Working Group on Calibration and Validation has coordinated the implementation pof an on-line validation system, supported by ESA (Weiss et al., 2014). The subgroup is coordinating with several long-term in-situ networks to improve the quantity and quality of validation data, for example by reviewing field sampling protocols (e.g., ICOS, NEON). Most importantly, the LPV subgroup compiled and distributed a community-reviewed best practices document for LAI intercomparison and validation. This document is referenced with a DOI (doi:10.5067/doc/ceoswgcv/lpv/lai.002). For more information see http://lpvs.gsfc.nasa.gov/LAI_home.html.

5.5.12.2 GCOS/CEOS Action T31; SS: T.7 (fAPAR) and T.8 (LAI)

Action: Operationalize the generation of FAPAR and LAI products as gridded global products at spatial resolution of 2 km or better over time periods as long as possible.
Who: Space agencies, coordinated through CEOS WGCV, with advice from GCOS and GTOS.
Time-Frame: 2012.
Performance Indicator: One or more countries or operational data providers accept the charge of generating, maintaining, and distributing global FAPAR products.
Annual Cost Implications: 10-30M US$ (10% in non-Annex-I Parties).

CEOS Entities:
- **CEOS Agency Leads:** TBD
- **CEOS Agency Contributors**: ESA, NASA, NOAA, EUMETSAT, JAXA, CSA
- **CEOS Coordination Mechanisms**: TBD

International Coordination Bodies: GTOS

Associated Organizations: TBD

Specific Deliverable(s):
- Specification of an algorithmic approach which produces consistent LAI and fAPAR products from the different contributing sensors. This includes re-processing of existing archives of the satellite observations and specification for future systems (*e.g.*, Sentinel 3,

VIIRS). The system shall produce the LAI/fAPAR estimates complete with specification of the uncertainty following methods defined in T29 and T30. The products shall be consistent and coherent with reference to LAI, fAPAR, albedo and phenology.

Accuracy, stability, horizontal resolution, and vertical resolution

ECV: Leaf area index (LAI) (SS: T.8) and Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)	**GCOS/CEOS Action T31**		
		Property	
		LAI	FAPAR
Accuracy	Target	Max(20%; 0.5)	max(10%; 0.05)
	Planned	TBD	TBD
Stability (/decade)	Target	max(10%; 0.25)	max(3%; 0.02)
	Planned	TBD	TBD
Horizontal resolution (km)	Target	0.25	0.25
	Planned	TBD	TBD

Key activities and time frames to meet deliverables (2011 – 2015)

- Agree on responsibility for operational processing between existing operational organizations (*e.g.*, EUMETSAT, NOAA, CSA) and research and development agencies (NASA, ESA, CCRS) – 2011
- Establish an algorithm intercomparison activity following the Radiation Transfer Model Intercomparison (RAMI) concept for models incorporating uncertainty derivations – 2012
- Develop a community-agreed specification of uncertainty that is traceable to the FCDR - 2012
- Implement agreed protocols for calibration and intercalibration - 2011
- Reprocess all contributing archives using agreed ancillary datasets (land-water masks, parameters for atmospheric correction et cetera) – 2012-15
- Establish a network for processing and reprocessing (grid or cloud concepts) and ensure archiving and open access to existing datasets are in place for an operational scheme - 2015
- Develop operational processors for the new sensor systems (*e.g.*, Sentinel 3 and VIIRS) that are compatible with the existing agreed algorithms following reconciliation – 2015

2015 Update

Operational product generation has commenced through NOAA and EUMETSAT. For example, NOAA's Climate Data Records Program has transitioned the production of LAI and fAPAR to operations (http://www.ncdc.noaa.gov/cdr/operationalcdrs.html). The records are global on a 0.05 by 0.05 degree grid and are produced daily from 1981-present. These records are also routinely updated and full documentation is available. However, to date community agreed specifications of uncertainty, reconciliation of algorithms and ancillary data have not been achieved for LAI and all contributing archives have not been therefore reprocessed to date.

5.5.13 Above-ground Biomass

Importance of this ECV

Above-ground biomass (AGB) is defined as total mass of living plant material per unit area in forests and woodlands. Vegetation biomass is a global store of carbon comparable in size to atmospheric carbon. AGB is an important fraction of the carbon stored in the terrestrial domain, and its dynamics play two major roles in the climate system:

- Photosynthesis withdraws CO_2 from the atmosphere and stores it as biomass, which then provides a source of soil carbon through plant detritus and mortality, with associated respiration.
- The amount of CO_2, CH_4, CO and aerosols emitted by fires depends on the quantity of biomass consumed.

Human activities such as deforestation and slash/burn agricultural practices contribute 6–17% of global anthropogenic CO_2 emissions to the atmosphere. Large uncertainties in emission estimates arise from inadequate data on the carbon density of forests and the regional rates of deforestation.

5.5.13.1 GCOS/CEOS Action T32; SS: N/A

Action: Develop demonstration datasets of above ground biomass across all biomes.
Who: Parties, space agencies, national institutes, research organizations, FAO in association with GTOS, TOPC, the GOFC-GOLD Biomass Working Group, and GFOI.
Time frame: 2012.
Performance Indicator: Availability of global gridded estimates of above ground biomass and associated carbon content.
Annual Cost Implications: 1-10M US$ (20% in non-Annex-I Parties).

The complete CEOS response to this action is under development.

2015 Update

CEOS has established an *ad hoc* Space Data Coordination Group (SDCG) for the Global Forest Observations Initiative (GFOI) to support developing countries in setting up national forest monitoring systems. This supports reporting in the REDD+ context and includes the production of above ground biomass data sets. Details can be found at http://gfoi.org/.

5.5.14 Soil Carbon

Importance of this ECV

Soils represent the largest terrestrial carbon pool. On seasonal to decadal time scales, carbon sinks may be explained by changes in above-ground biomass, but on longer time scales soil carbon stocks become more relevant. Globally, the largest soil carbon stocks are primarily located in wetlands and peatlands, most of which are found on permafrost and in the Tropics.

This soil carbon is vulnerable to variations in the hydrological cycle as well as to modifications of permafrost dynamics (in the boreal zone) due to climate change. Changes in soil organic carbon are largely influenced by anthropogenic activities, particularly through the conversion of natural ecosystems to agricultural land.

5.5.14.1 GCOS/CEOS Action T34; SS: N/A

Action: Develop globally gri**d**ded estimates of terrestrial carbon flux from *in situ* observations and satellite products and assimilation/inversions models.
Who: Reanalysis centres and research organisations, in association with national institutes, space agencies, and FAO/GTOS (TCO and TOPC).
Time Frame: 2014-2019.
Performance indicator: Availability of data assimilation systems and global time series of maps of various terrestrial components of carbon exchange (e.g., Gross Primary Production (GPP), Net Ecosystem Production (NEP), and Net Biome Production (NBP)).
Annual Cost Implications: 10-30M US$ (Mainly by Annex-I Parties).

The CEOS Carbon Task Force (CTF) will be responsible for carrying out this action. CEOS established the CTF to coordinate the response from space agencies to the *GEO Carbon Strategy Report*. The CTF will:

- Take into account information requirements of both the UNFCCC and IPCC and consider how future satellite missions will support them;
- Also take account of, and be consistent with, the GCOS and GEO Implementation Plans; and
- Help definition of next generation missions for individual agencies.

The CTF is developing a comprehensive action plan for observations related to the carbon cycle that will include atmospheric, oceanic, and land observations. The oceanic and land observations will include many of the ECVs covered in this document: ocean colour, surface wind, temperature and salinity, and land biomass and leaf area index. The atmospheric component requires satellite instruments with greenhouse gas measuring capabilities. Current satellites with such capabilities include SCIAMACHY and GOSAT/IBUKI. Planned satellite missions include: OCO-2, at the end of 2012, SENTINEL 5P, OCO-3, CARBONSAT, GOSAT-2, and a German/French Climate mission in 2014, MicroCarb in 2016, SENTINEL 5 in 2018, and JEM-DIAL in 2020.

2015 Update

CEOS has published a Strategy for Carbon Observations from Space (http://ceos.org/document_management/Publications/WGClimate_CEOS-Strategy-for-Carbon-Observations-from-Space_Apr2014.pdf) and is implementing a number of the actions identified in the strategy report through the appropriate Virtual Constallations and Working Groups.

5.5.15 Fire Disturbance

Importance of this ECV

The emissions of greenhouse gases and aerosols resulting from fires are important climate forcing factors. Fires also have a large influence on the storage and flux of carbon in the biosphere and atmosphere and can cause long-term changes in land cover, affecting surface-atmosphere transfer of radiation, heat, and water vapor. Fires can occur naturally, set off by lightning strikes, for example, or due to human activities, slash and burn agricultural practices, for instance.

5.5.15.1 GCOS/CEOS Action T35; SS: T.10

Action: Reanalyse the historical fire disturbance satellite data (1982 to present).
Who: Space agencies, working with research groups coordinated by GOFC-GOLD.
Time-Frame: By 2012.
Performance Indicator: Establishment of a consistent dataset, including the globally available 1 km AVHRR data record.
Annual Cost Implications: 1-10M US$ (Mainly by Annex-I Parties).

Associated Organizations: ESA Climate Change Initiative CCI (esa.cci.int)

Key activities and time frames to meet deliverables (2011 – 2015)

- The ESA Climate Change Initiative initiated a Fire CCI Project to develop a monthly global burnt area maps prototyped on the period 1981-2015.

The complete CEOS response to this action is under development.

2015 Update

This action was discussed at the 2014 GOFC-GOLD Fire Implementation Team meeting in College Park, MD, and it was agreed it was more beneficial for stakeholders to focus on ensuring future continuity with the MODIS data record. The rescue of the 1-km AVHRR data record is overarching issue. Agencies should make a coordinated data rescue effort (including HRPT from various DB operators), which would be the pre-requisite for generating a 1km-based fire data record. There have been some previous efforts, such as using USGS and NOAA archives, but none of these appear to be complete.

The Fire_cci project is developing monthly global burnt area maps prototyped on the period 1981-2015 (AVHRR, MERIS, VGT, Proba-V, MODIS, Sentinel-3, as well as Sentinel-2 for small fires in Africa). In perennially cloud covered areas complementary information derived from SAR is included.
To advance on product quality it a unique validation database has been built consisting of high resolution optical satellite images collected over 200 globally distributed sites.
See: http://www.esa-fire-cci.org

References:

Hantson, S., M. Padilla, D. Corti, and E. Chuvieco, 2013: Strengths and weaknesses of MODIS hotspots to characterize global fire occurrence. *Remote Sens. Environ.*, **131**, 152–159, doi:10.1016/j.rse.2012.12.004.

Hollmann, R., and Coauthors, 2013: The ESA Climate Change Initiative: Satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, 94, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Mouillot, F., M. G. Schultz, C. Yue, P. Cadule, K. Tansey, P. Ciais, and E. Chuvieco, 2014: Ten years of global burned area products from spaceborne remote sensing—A review: Analysis of user needs and recommendations for future developments. *Int. J. Appl. Earth Obs. Geoinfo.*, **26**, 64–79, doi:10.1016/j.jag.2013.05.014.

Padilla, M., S. Stehman, J. Litago, and E. Chuvieco, 2014: Assessing the temporal stability of the accuracy of a time series of burned area products. *Remote Sens.*, **6**, 2050–2068, doi:10.3390/rs6032050.

Padilla, M., and Coauthors, 2015: Comparing the accuracies of remote sensing global burned area products using stratified random sampling and estimation. *Remote Sens. Environ.*, **160**, 114–121, doi:10.1016/j.rse.2015.01.005.

Padilla, M., S. V. Stehman, and E. Chuvieco, 2014: Validation of the 2008 MODIS-MCD45 global burned area product using stratified random sampling. *Remote Sens. Environ.*, **144**, 187–196. doi:10.1016/j.rse.2014.01.008.

Poulter, B., and Coauthors, 2015: Sensitivity of global terrestrial carbon cycle dynamics to variability in satellite-observed burned area. *Global Biogeochem. Cycles*, **29**, 207–222, doi:10.1002/2013GB004655.

Yue, C., and Coauthors, 2014: Modelling the role of fires in the terrestrial carbon balance by incorporating SPITFIRE into the global vegetation model ORCHIDEE – Part 1: simulating historical global burned area and fire regimes. *Geosci. Model Develop.*, **7**, 2747–2767, doi:10.5194/gmd-7-2747-2014.

5.5.15.2 GCOS/CEOS Action T36; SS: T.10

Action: Continue generation of consistent burnt area, active fire, and FRP products from low orbit satellites, including version intercomparisons to allow un-biased, long-term record development.
Who: Space agencies, in collaboration with GOFC-GOLD.
Time-Frame: Continuous.
Performance Indicator: Availability of data.
Annual Cost Implications: 1-10M US$ (Mainly by Annex-I Parties).

The complete CEOS response to this action is under development.

2015 Update

VIIRS is now entering full production phase. NASA will generate a burned are product and both NASA and NOAA are implementing a consistent MODIS-like active fire algorithm (including FRP). NASA will generate the full suite (Levels 2 and 3) while NOAA will run the compatible Level 2 real-time product. For active fires only dynamic continuity is possible due to sensor differences. The community needs to ensure continuity on the mid-morning orbit with Terra MODIS from Sentinel-3 SLSTR.

More info on VIIRS fire: http://viirsfire.geog.umd.edu/

Key publications:

Csiszar, I., W. Schroeder, L. Giglio, E. Ellicott, K. P. Vadrevu, C. O. Justice, and B. Wind, 2014: Active fires from the Suomi NPP Visible Infrared Imaging Radiometer Suite: Product status and first evaluation results. *J. Geophys. Res. Atmos.*, **119**, 803–816, doi:10.1002/2013JD020453.

Schroeder, W., P. Oliva, L. Giglio, and I. A. Csiszar, 2014: The New VIIRS 375 m active fire detection data product: Algorithm description and initial assessment. *Remote Sens. Environ.*, **143**, 85–96, doi:10.1016/j.rse.2013.12.008.

5.5.15.3 GCOS/CEOS Action T37; SS: T.10

Action: Develop and apply validation protocol to fire disturbance data.
Who: Space agencies and research organizations.
Time-Frame: By 2012.
Performance Indicator: Publication of accuracy statistics.
Annual Cost Implications: 1-10M US$ (Mainly by Annex-I Parties

CEOS Entities:

- **CEOS Agency Leads:** ESA
- **CEOS Agency Contributors**: NASA
- **CEOS Coordination Mechanisms**: TBD

International Coordination Bodies: GOFC-GOLD Fire Implementation Team

Associated Organizations: TBD

Specific Deliverable #1:

The deliverable is a community-accepted validation protocol for burned area. The validation protocol comprises a description of the methodology used to generate validation datasets (Part 1), a description of the global sampling framework to achieve unbiased representation of fire activity over space and time (Part 2), and standards for reporting the accuracy of global burned area products from coarse resolution data.

Specific Deliverable #2

This deliverable is a database of validation data that follows the protocol described above and is available to the scientific community.

2015 Update

The CEOS WGCV subgroup for Land Product Validation provides updated information on intercomparison and validation of fire products, including an overview of good practice and reference data sets (https://lpvs.gsfc.nasa.gov/fire_home.html). Significant process was made with respect to validation method development, burned area product intercomparison for selected years and temporal stability assessment in the framework of the ESA CCI program. Regarding reference data sets for validation, the ongoing development of higher resolution products will require a new generation (i.e., even higher resolution) of reference data. In an ongoing joint action of GCOS-TOPC experts and CEOS WGCV LPV, definitions of accuracy metrics are currently being reviewed in order to allow for an unambiguous validation of fire products.

5.5.15.4 GCOS/CEOS Action T39; SS: T10

Action: Develop set of active fire and FRP products from the global suite of operational geostationary satellites.
Who: Through operators of geostationary systems, via CGMS, GSICS, and GOFC-GOLD
Time-Frame: Continuous
Performance Indicator: Availability of products
Annual Cost Implications: 1-10M US$ (Mainly by Annex-I Parties)

CEOS Entities:

- **CEOS Agency Leads:** NOAA
- **CEOS Agency Contributors**: EUMETSAT
- **CEOS Coordination Mechanisms**: TBD

International Coordination Bodies: GOFC-GOLD Fire Implementation Team, CGMS, GSICS

Associated Organizations: TBD

Specific Deliverable(s):
The deliverable is standardized long-term active fire and Fire Radiative Power (FRP), (Watts or J/s) products from the global suite of operational geostationary satellites.

The active fire product provides information on the location of pixels containing fire activity and associated metadata. Detailed metadata is crucial for the proper interpretation of active fire products especially given the significant differences in the fire monitoring capabilities of the global geostationary satellite systems. Metadata should include specifics such as: an indication of the fire pixel confidence level; satellite and processing coverage regions; algorithm block-out zones associated with viewing geometry, solar reflection contamination, and specific biomes; data and algorithm anomalies and limitations; instrument saturation; an opaque cloud mask; atmospheric attenuation information; and geo-location characterization uncertainties.

FRP is the time derivative of the fire radiative energy, which is proportional to the biomass consumed by the fire. Multiple FRP observations can in principle provide estimates of total fire emissions (CO_2, particles less than 2.5 micrometers in diameter (PM 2.5), etc.) through estimating time-integrated Fire Radiated Energy (FRE).

Fire is a global phenomenon with large variability in both time and space. It is an important ecosystem disturbance factor and contributes to atmospheric emissions on multiple time scales. Active fires have a strong diurnal component and geostationary monitoring is essential for providing a more complete view of regional, diurnal, seasonal, and interannual variability in fire activity. Detection of active fires is also required by some burned area product algorithms. Active fire information can serve as part of the validation process for burned area products and diurnal information on emissions is vital for modeling applications. In recent years modelers have shown interest in utilizing fire radiative energy/power to characterize emissions. One may assert that the total FRE of a fire is directly related to mass consumed by the heat of combustion, which can then be related to PM 2.5, CO_2 and other emissions.

Due to the disparity and inadequacy in regional and national fire reporting protocols, satellite remote sensing represents the most suitable and cost effective method for consistent, long-term regional and global scale monitoring. Over the past 10 years the use of geostationary satellites for both diurnal fire detection and characterization has grown appreciably with applications in hazards monitoring, fire weather forecasting, climate change research, emissions monitoring, aerosol and trace gas transport modeling, air quality, and land-use and land-cover change detection. Current (GOES-E/-W/-South America, Meteosat-8/-9, Multi-Functional Transport Satellite (MTSAT)-1R/-2, FY-2C/2D) and future (Indian INSAT-3D, Russian GOMS Elektro L MSU-GS, Korean COMS) operational geostationary platforms will enable nearly globalgeostationary fire monitoring with significant improvements in capabilities over the next 5-7 years (*e.g.*, GOES-R, MTG).

The development of the Global Geostationary Fire Monitoring Network is coordinated through the Global Observation of Forest and Landcover Dynamics (GOFC-GOLD) Fire Mapping and Monitoring Implementation Team (IT). The GOFC-GOLD Fire IT organized a meeting in 2011 in Stresa, Italy, where the status of the network was discussed. A follow-up workshop is scheduled for 2013 in Germany.

Accuracy, stability, horizontal resolution, and vertical resolution

ECV: Fire disturbance	**GCOS/CEOS Action T39**				
	Property				
		Burnt area	Active fires	Fire radiative power (polar satellites)	Fire radiative power (geostationary satellites)
Accuracy	Target	15% (error of omission and commission), compared to 30m observations	5% error of commission 30% error of omission compared to 30m spatial resolution detections (based on per-fire comparisons)		
	Planned				
Stability (%/decade)	Target	15% (error of omission and commission), compared to 30m observations	N/A		
	Planned				
Horizontal resolution (km)	Target	0.25	1	1	1
	Planned				

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

- NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) currently provides Wildfire Automated Biomass Burning Algorithm (WF_ABBA) active fire locations and FRP in various formats for GOES-E/-W, Meteosat-9, and MTSAT-1. WF_ABBA fire masks and metadata have not yet been released as part of the NESDIS operational fire product, although they are available from University of Wisconsin- Madison Cooperative Institute for Meteorological Satellite Studies (CIMSS). The time frame for operational release is currently unknown.
- EUMETSAT is implementing a global geostationary fire product.
- Provided the data are accessible in near real-time and well-calibrated/navigated, the WF_ABBA will be adapted to Communication, Ocean, and Meteorological Satellite (COMS), Geostationary Orbit Meteorological Satellite (GOMS) Elektro L MSU-GS over the next 2 years. Funding is being sought for the operational implementation of the extended product by NOAA/NESDIS.
- UW-Madison CIMSS has delivered the initial GOES-R Advanced Baseline Imager (ABI) fire algorithm and will continue to evaluate and update it.

2015 Update

GOES-R is planned to be launched next year and the ABI product will be a significant improvement over the current GOES. NOAA will generate and operational product. Himawari-8 was launched recently with ABI capability. MTG FCI will also have similar capability. However, the issues of inconsistency between the various missions and data access remain for at least the next several years as the new generation sensors are phased in.

5.6 Cross-cutting Actions

While most of the GCOS IP-10 requirements for satellite-based products are framed in terms of actions for space agencies that are specific to one of the atmospheric, oceanic, or terrestrial domains, the GCOS IP-10 also lists several generic, all-embracing actions requiring the participation of all CEOS Agencies in their implementation.

5.6.1 Continuity of Satellite Systems and Data Products

5.6.1.1 GCOS/CEOS Action C8: SS: N/A

Action: Ensure continuity and over-lap of key satellite sensors; recording and archiving of all satellite metadata; maintaining appropriate data formats for all archived data; providing data service systems that ensure accessibility; undertaking reprocessing of all data relevant to climate for inclusion in integrated climate analyses and reanalyses, undertaking sustained generation of satellite-based ECV products.
Who: Space agencies and satellite data reprocessing centres.
Time-Frame: Continuing, of high priority.
Performance Indicator: Continuity and consistency of data

CEOS, WMO and CGMS support the coordination of civil space-borne observations of the Earth. The coordination groups will continue to serve as a focal point for international coordination of space-related Earth observation activities, mission planning, and in the development of compatible data products, formats, services, applications and policies.

2015 Update

The CEOS-CGMS Working Group on Climate has been established with the over-arching goal to improve the systematic availability of Climate Data Records through the coordinated implementation, and further development of the architecture for climate monitoring from space. The objectives include –

- Provision of a structured, comprehensive and accessible view as to what Climate Data Records are currently available from satellite missions of CEOS and CGMS members or their combination;
- Creation of the conditions for delivering further Climate Data Records, including multi-mission Climate Date Records, through best use of available data to fulfil GCOS requirements (e.g. by identifying and targeting cross-calibration or re-processing gaps/shortfalls);

- Optimization of the planning of future satellite missions and constellations to expand existing and planned Climate Data Records, both in terms of coverage and record length, and to address possible gaps with respect to GCOS requirements

5.6.2 Distributed Data Services

5.6.2.1 GCOS/CEOS Action C21; SS: N/A

Action: Implement modern distributed data services, drawing on the experiences of the WIS as it develops, with emphasis on building capacity in developing countries and countries with economies in transition, both to enable these countries to benefit from the large volumes of data available world-wide and to enable these countries to more readily provide their data to the rest of the world. **Who:** Parties' national services and space agencies for implementation in general, and Parties through their support of multinational and bilateral technical cooperation programmes, and the GCOS Cooperation Mechanism. **Time-Frame:** Continuing, with particular focus on the 2011-2014 time period. **Performance Indicator:** Volumes of data transmitted and received by countries and agencies. **Annual Cost Implications:** 30-100M US$ (90% in non-Annex-I Parties).

CEOS, through its Working Group on Information Systems and Services (WGISS), will coordinate space agency contributions to implementing modern distributed data services. The WGISS Technology Exploration Interest Group and CEOS WGISS Integrated Catalog (CWIC) project will work with the Parties national services and space agencies to coordinate the implementation of full information processing chain from the initial ingestion of satellite data into archives through to the incorporation of derived information into end-user applications.

2015 Update

The CEOS Working Group on Information Systems and Services (WGISS - http://ceos.org/ourwork/workinggroups/wgiss/) has instituted an opensearch protocol to allow for the sharing of search results across all CEOS dta collections.

Summary

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 tight 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 between 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.

Appendix 1 GCOS Guideline for Satellite-based Datasets and Products

Summary of GCOS Guideline for Satellite-based Datasets and Products

1. Full description of all steps taken in the generation of FCDRs and ECV products, including algorithms used, specific FCDRs used, and characteristics and outcomes of validation activities
2. Application of appropriate calibration/validation activities.
3. Statement of expected accuracy, stability and resolution (time, space) of the product, including, where possible, a comparison with the GCOS requirements.
4. Assessment of long-term stability and homogeneity of the product.
5. Information on the scientific review process related to FCDR/product construction (including algorithm selection), FCDR/product quality and applications.
6. Global coverage of FCDRs and products where possible.
7. Version management of FCDRs and products, particularly in connection with improved algorithms and reprocessing.
8. Arrangements for access to the FCDRs, products and all documentation.
9. Timeliness of data release to the user community to enable monitoring activities.
10. Facility for user feedback.
11. Application of a quantitative maturity index if possible.
12. Publication of a summary (a webpage or a peer-reviewed article) documenting point by point the extent to which this guideline has been followed

Effective monitoring systems for climate should adhere to the following principles[14]:

1. The impact of new systems or changes to existing systems should be assessed prior to implementation.
2. A suitable period of overlap for new and old observing systems is required.
3. The details and history of local conditions, instruments, operating procedures, data processing algorithms and other factors pertinent to interpreting data (i.e., metadata) should be documented and treated with the same care as the data themselves.
4. The quality and homogeneity of data should be regularly assessed as a part of routine operations.
5. Consideration of the needs for environmental and climate-monitoring products and assessments, such as IPCC assessments, should be integrated into national, regional and global observing priorities.
6. Operation of historically-uninterrupted stations and observing systems should be maintained.

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[14] *The ten basic principles (in paraphrased form) were adopted by the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) through decision 5/CP.5 at COP-5 in November 1999. This complete set of principles was adopted by the Congress of the World Meteorological Organization (WMO) through Resolution 9 (Cg-XIV) in May 2003; agreed by the Committee on Earth Observation Satellites (CEOS) at its 17th Plenary in November 2003; and adopted by COP through decision 11/CP.9 at COP-9 in December 2003.*

7. High priority for additional observations should be focused on data-poor regions, poorly observed parameters, regions sensitive to change, and key measurements with inadequate temporal resolution.
8. Long-term requirements, including appropriate sampling frequencies, should be specified to network designers, operators and instrument engineers at the outset of system design and implementation.
9. The conversion of research observing systems to long-term operations in a carefully-planned manner should be promoted.
10. Data management systems that facilitate access, use and interpretation of data and products should be included as essential elements of climate monitoring systems.

Furthermore, operators of satellite systems for monitoring climate need to:

(a) Take steps to make radiance calibration, calibration-monitoring and satellite-to-satellite cross-calibration of the full operational constellation a part of the operational satellite system; and

(b) Take steps to sample the Earth system in such a way that climate-relevant (diurnal, seasonal, and long-term interannual) changes can be resolved.

Thus satellite systems for climate monitoring should adhere to the following specific principles:

11. Constant sampling within the diurnal cycle (minimizing the effects of orbital decay and orbit drift) should be maintained.
12. A suitable period of overlap for new and old satellite systems should be ensured for a period adequate to determine inter-satellite biases and maintain the homogeneity and consistency of time-series observations.
13. Continuity of satellite measurements (i.e. elimination of gaps in the long-term record) through appropriate launch and orbital strategies should be ensured.
14. Rigorous pre-launch instrument characterization and calibration, including radiance confirmation against an international radiance scale provided by a national metrology institute, should be ensured.
15. On-board calibration adequate for climate system observations should be ensured and associated instrument characteristics monitored.
16. Operational production of priority climate products should be sustained and peer-reviewed new products should be introduced as appropriate.
17. Data systems needed to facilitate user access to climate products, metadata and raw data, including key data for delayed-mode analysis, should be established and maintained.
18. Use of functioning baseline instruments that meet the calibration and stability requirements stated above should be maintained for as long as possible, even when these exist on decommissioned satellites.
19. Complementary *in situ* baseline observations for satellite measurements should be maintained through appropriate activities and cooperation.
20. Random errors and time-dependent biases in satellite observations and derived products should be identified

Appendix 2 Climate Actions for Space-based Observations With 2015 Updates

5.3.2.1 GCOS/CEOS Action A8; SS: A.2

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: 20-40M US$(for generation of climate products, assuming missions funded for other operational purposes) (Mainly by Annex-I Parties).

2015 Update

Specific Deliverable #1

- TRMM has continued to be operated; it is out of fuel and will be passivized in early 2015 when its orbit decays to a set altitude (325 km). The TMI is operating continuously, while the radar is only available when the altitude is in set ranges.
- GPM was launched into a 65° orbit on 27 February 2014 (UTC), and Day-1 GMI and DPR products were released in stages through the summer.
- The initial GPM-era constellation consists of microwave imagers (DMSP F15 SSMI [limited]; DMSP F16, F17, F18, and F19 SSMIS; TRMM TMI; GCOM-W1 AMSR2; GPM GMI) and microwave sounders (NOAA-18, NOAA-19, Metop-A, and Metop-B MHS; Megha-Tropiques SAPHIR; SNPP ATMS).
- The pre-GPM PC calibrator was the TRMM observatory; it is planned that intercalibration of the TRMM and GPM observatories will allow the entire TRMM-GPM era to be treated as a continuous record, a long time series that is now viewed as critical for the long-term records demanded for societal applications, including climate studies.
- Upon reflection, "completely characterize" seems unachievable for sensors; "carefully" is a reasonable standard that agencies strive to achieve.

Specific Deliverable #2

The satellite operators work through GSICS to ensure calibration and geolocation at Level 1b.

Specific Deliverable #3

The GPM project's XCal Team developed and maintains intercalibrations of all radiometers to the Core Observatory reference at Level 1c.

Specific Deliverable #4

GPM is developing a physically based Bayesian retrieval system that can be applied to both imagers and sounders, GPROF2014, which is designed to be useful over land, coast, ocean, and frozen surfaces. Independently, NOAA is pursuing a more assimilation-like approach that applies to both imagers and sounders, MiRS.

Specific Deliverable #5

The output of GPROF2014 applied to all the microwave sensors in the constellation is freely available as individual satellite orbits at Level 2 – IFOVs in the original scan/footprint coordinates.

Additional Comments

1. Computations of the precipitation ECV rest not only on the microwave constellation currently considered the CEOS-VPC, but also on the geosynchronous constellation that provides increasingly rich multi-spectral data on relatively fine time intervals. As such, "the constellation" the community needs really encompasses both sets of satellites.

2. The future of the microwave constellation (and even the Indian Ocean segment of the geo-constellation) is open to question. It takes a decade or more to carry a satellite from concept to launch, so it seems essential to have a planning activity as part of the 5-year plan. One can't open discussions at the end of one 5-year period and assume that satellites will appear to fill the need as legacy satellites age off of the system.

3. The current statement on the necessary number of microwave constellation satellites is that we need the time between observations to be no more than 3 hours. That's not an average, that's the maximum. The current uncoordinated collection of satellites makes it hard to achieve this, but we should go for some standard like "75% of gaps be <3 hours".

Reference

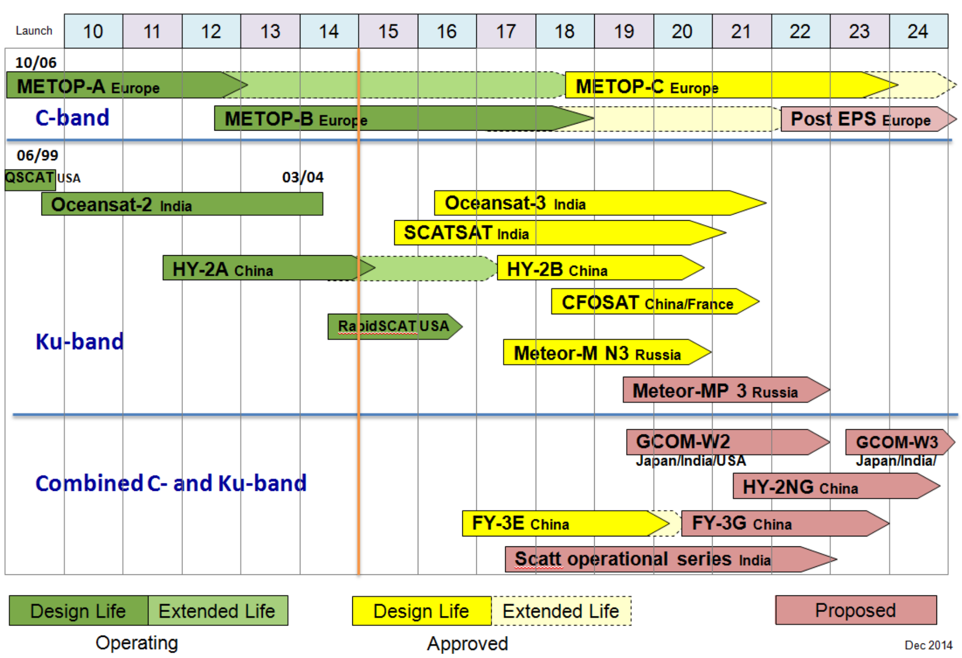
Hou, A. Y., R. K. Kakar, S. Neeck, A. A. Azarbarzin, C. D. Kummerow, M. Kojima, R. Oki, K. Nakamura, and T. Iguchi, 2014: The Global Precipitation Measurement Mission. *Bull. Amer. Meteor. Soc.*, **95**, 701–722, doi:10.1175/BAMS-D-13-00164.1

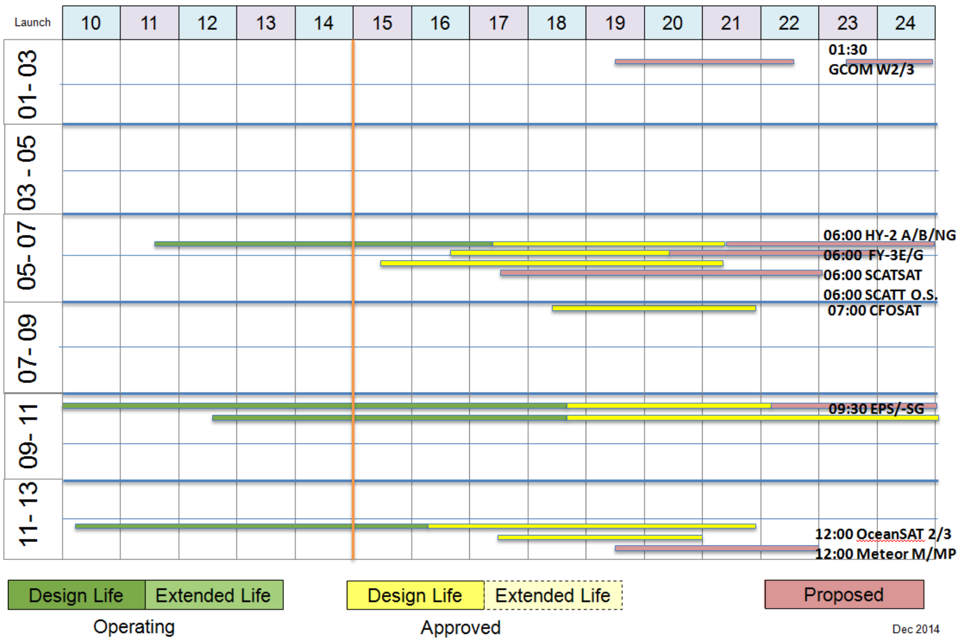
5.3.3.1 GCOS/CEOS Action A11; SS: A.1

Action: Ensure continuous generation of wind-related products from AM and PM satellite scatterometers or equivalent observations.
Who: Space agencies.
Time-Frame: Continuous.
Performance Indicator: Long-term satellite observations of surface winds every six hours.
Annual Cost Implications: 1-10M US$ (Mainly by Annex-I Parties).

2015 Update

NASA's International Space Station Rapid Scatterometer, or ISS–RapidScat, is the first near-global scientific Earth-observing climate instrument specifically designed and developed to operate from the exterior of the space station. The experimental mission will measure near-surface ocean wind speed and direction in Earth's low and mid-latitudes in any kind of weather except heavy rain. ISS-RapidScat joins in orbit the EUMETSAT ASCAT, which is in morning polar orbit as of April 2015. Calibration and validation activities as well as data acess activities are being coordinated by the CEOS ocean surface vector wind virtual constellation (OSVW-VC - http://ceos.org/ourwork/virtual-constellations/osvw/). Space agency plans for ocean surface vector wind instrument frequency coverage and spatial sampling are shown below.





5.3.4 Upper-air Wind Speed and Direction; SS: A.4

Satellite Supplement Product A.4

There is no specific action in GCOS IP-10, but the Satellite Supplement includes the following target requirements listed as Product A.4 Upper air wind retrievals

ECV: Upper air wind	**GCOS/CEOS Action**	
	Property	
	Upper air wind	
Accuracy	Target	20 m/s, 20 degrees
	Planned	TBD
Stability (/decade)	Target	0.5 m/s, 5 degrees
	Planned	TBD
Horizontal resolution (km)	Target	10
	Planned	TBD
Vertical resolution (km)	Target	0.5
	Planned	TBD

Upper air wind speed and direction are obtained primarily from geostationary satellites by tracking the motion of clouds or moisture features in visible and infrared images over time. This technique is also applied to polar orbiting satellites in the arctic regions where there are short revisit times. The WMO SCOPE-CM program includes a coordinated effort to reprocess geostationary winds. In the near future, ESA's Atmospheric Dynamics Mission Aeolus (ADM-Aeolus) – scheduled for launch in 2014 – will provide lidar wind profiles with radiosonde-like quality wind speed and direction data.

2015 Update

A collaborative project within the Sustained and coordinated processing of Environmental Satellite data for Climate Monitoring (SCOPE-CM) is coordinating re-processing of atmospheric motion vectors (AVMs). Please visit the web site of this project for details: http://www.scope-cm.org/wpcms/wp-content/uploads/2014/01/SCM_10_AMV_geo_leo.pdf)

5.3.5.1 GCOS/CEOS Action A19; SS: N/A

Action: Implement and evaluate a satellite climate calibration mission, *e.g.,* CLARREO.
Who: Space agencies (*e.g.,* NOAA, NASA, etc).
Time-Frame: Ongoing.
Performance Indicator: Improved quality of satellite radiance data for climate monitoring.
Annual Cost Implications: 100-300M US$ (Mainly by Annex-I Parties).

2015 Update

The lack of a GCOS Climate Calibration Mission remains a serious gap in the GCOS climate observing system. No space agency has yet started such a mission although the U.S. (NASA) and the UK (NPL) has invested substantially in pre-phase A science, instrument, and mission studies relevant to such a mission. A summary of the status is given below.

In 2007, the U.S. National Research Council (NRC, 2007) recommended CLARREO (Climate Absolute Radiance and Refractivity Observatory) as a NASA space-based mission with goals consistent with the GCOS Climate Calibration Mission. The CLARREO mission includes a reflected solar spectrometer (320 to 2300 nm spectral coverage, 4 nm spectral sampling, and an SI traceable accuracy requirement of 0.3% of the Earth's mean reflectance at 95% confidence). It also includes an infrared spectrometer (200 to 2000 cm-1 spectral coverage, 0.5 cm-1 spectral resolution, and an SI traceable accuracy requirement of 0.07K at 95% confidence). Both spectrometers are designed to serve as in orbit calibration references for space based instruments that include spectrometers, band pass radiometers and broadband radiation radiometers (Wielicki et al. 2013 and references therein). These spectrometers are also designed to provide reflected solar and infrared spectra capable of serving as spectral fingerprints of climate change (e.g. Feldman et al. 2011, Huang et al., 2010).

The WMO GSICS (Global Space Based Intercalibration System) has called for the CLARREO mission (or equivalent) to provide reference spectrometers for GSICS intercalibration of both low earth orbit and geostationary orbit instruments (Goldberg et al., 2011).

Extensive pre-phase A study has been done on the CLARREO mission science, instruments and mission leading to a successful Mission Concept Review in November, 2010 An overview of these studies and the mission design can be found in Wielicki et al. 2013 as well as the CLARREO mission home page at clarreo.larc.nasa.gov). In early 2011, however, NASA's Earth Science budget was reduced by roughly $1.5 billion dollars, leading to a delay of the CLARREO mission with a current launch date of no earlier than 2023. The mission continues pre-phase A studies focusing on reducing instrument size, cost, and risk. These studies are also focused on further clarifying the mission science requirements and understanding analysis algorithms for reference intercalibration of sensors as well as uncertainties in spectral fingerprinting. Efforts are underway to explore possible international collaboration on this mission, with either the UK or India.

In the UK, the TRUTHS mission (Traceable Radiometry Underpinning Terrestrial- and Helio-Studies) was proposed to the ESA Explorer Earth Explorer-8 announcement but was not selected for flight due to cost limitations. TRUTHS provides an alternative method to achieve the reflected solar portion of the GCOS 5.3.5 Climate Calibration Mission (Fox et al., 2011, and http://www.npl.co.uk/TRUTHS). Individual elements of the CLARREO mission (infrared or reflected solar) have also been proposed to NASA's small Venture class missions, but are not a good fit to the cost caps and programmatic design of the Venture opportunity. Neither the NASA Venture program nor the ESA Earth Explorer are designed for long term climate monitoring mission goals.

The CLARREO mission studies to date have been used to estimate the world economic value of advanced much higher accuracy climate observations, resulting in an estimate of $12 Trillion U.S. dollars in Net Present Value (3% discount rate) (Cooke et al. 2014). This value suggests a return on investment of roughly 50 to 1 if investments in climate observations were tripled from current levels to allow a more rigorous and more complete international climate observing system.

Efforts continue in the U.S. and UK to accelerate launch of a Climate Calibration Observatory, but none of these efforts has yet advanced beyond pre-phase A studies, primarily due to funding limitations in UK, ESA and NASA budgets. The technologies for both the CLARREO and TRUTHS missions have been advanced to the TRL-6 levels required for mission starts. Demonstration laboratory instruments have been built at both NASA Langley and University of Wisconsin for the infrared interferometer, as well as at both NASA Goddard Space Flight Center and University of Colorado LASP in order to further reduce mission risk and cost. The U.S. National Institute of Standards and Technology (NIST) has been a partner in calibration verification of these new instrument designs. As part of this effort, NIST has been developing improved SI standards for wavelengths between 1000 and 2500 nm in the reflected solar spectrum and between 100 and 600 cm-1 in the infrared spectrum.

References:

Cooke, R., B. A. Wielicki, D. F. Young, and M. G. Mlynczak, 2014: Value of information for climate observing systems. *Environ. Syst. Decis.*, **34**, 98–109, doi:10.1007/s10669-013-9451-8.

Feldman, D. R., C. A. Algieri, W. D. Collins, Y. L. Roberts, and P. A. Pilewskie, 2011: Simulation studies for the detection of changes in broadband albedo and shortwave nadir reflectance spectra under a climate change scenario. *J. Geophys. Res. Atmos.*, **116**, D24103, doi:10.1029/2011JD016407.

Fox, N., A. Kaisser-Weiss, W. Schmutz, K. Thome, D. Young, B. Wielicki, R. Winkler, and E. Woolliams, 2011: Accurate radiometry from space: An essential tool for climate studies. *Philos. Trans. Roy. Soc.*, **369A**, 4028–4063, doi:10.1098/rsta.2011.0246.

Goldberg, M., and Coauthors, 2011: The Global Space-Based Inter-Calibration System (GSICS). *Bull. Amer. Meteor. Soc.*, **92**, 467–475.

Huang, Y., S. Leroy, P. J. Gero, J. Dykema, and J. Anderson, 2010: Separation of longwave climate feedbacks from spectral observations. *J. Geophys. Res. Atmos.*, **115**, D07104, doi:10.1029/2009JD012766.

NRC, 2007: Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond. National Academy Press, 428 pp.

Wielicki, B. A., and Coauthors, 2013: Climate Absolute Radiance and Refractivity Observatory (CLARREO): Achieving climate change absolute accuracy in orbit. *Bull. Amer. Meteor. Soc.*, **94**, 1519–1539.

5.3.6.1 GCOS/CEOS Action A20; SS: A.3.2

Action: Ensure the continued derivation of MSU-like radiance data, and establish FCDRs from the high-resolution IR sounders, following the GCMPs.
Who: Space agencies.
Time-Frame: Continuing.
Performance Indicator: Quality and quantity of data; availability of data and products.
Annual Cost Implications: 1-10M US$ (for generation of datasets, assuming missions, including overlap and launch-on-failure policies, are funded for other operational purposes) (Mainly by Annex-I Parties).

2015 update

Derived MSU-like radiance data include two types of products: recalibrated/inter-calibrated swath radiance FCDRs and channel-based atmospheric layer mean temperature TCDRs derived from averaging swath radiances over grid cells. Observations from four microwave and infrared temperature sounders including MSU (microwave), AMSU (microwave), SSU (infrared), and ATMS (microwave) onboard historical and currently operating polar orbiting satellites from NOAA, NASA EOS, and European MetOp were used in these developments. Three organizations were involved in developing the products in which NOAA is a lead agency developing both MSU-like FCDRs and TCDRs. The other two agencies, UAH and RSS, focused on deriving TCDRs. Some products were developed by all three agencies which are not only used for climate change monitoring and investigations, but also for mutual validation for improvement of merging algorithms. On the other hand, some other products (e.g., SSU related products) may have been developed by only one agency. Specific deliverables were proposed in the implementation plans for the period of 2010-2015 including both atmospheric temperature TCDRs (specific deliverable #1) radiance FCDRs (specific deliverable #2) development. Many accomplishments were achieved during this period and below are a summary based on proposed products.

For Specific Deliverable #1

- AMSU-only layer temperature time series from 1998 to present for channels 4-14 from the lower-troposphere to the upper stratosphere: NOAA has completed such a data set for all proposed AMSU-A channels 4-14 from 1998 to 2011. Details on merging algorithms and dataset characteristics can be seen from the publication on this dataset in Wang and Zou (2014). RSS has completed the AMSU-A stratospheric channels 9-14.

- Merged SSU/AMSU layer temperatures for the middle to upper stratospheres from 1978 to present: The raw SSU data contained multiple drifting issues that were not well studied and documented during the early stage of the satellite operations. NOAA has recently made a big effort in addressing SSU issues and to develop SSU-only temperature time series. The release of the first version of the NOAA SSU temperature climate data record in 2012 sparked community debate on the stratospheric temperature trends (Thompson et al. 2012). To address community concerns, NOAA further developed a recalibrated SSU swath radiance FCDR and an updated version of the SSU temperature dataset based on improved calibration and bias correction schemes. The new radiance FCDR and the updated SSU temperature datasets are described in details in Zou et al. (2014).

Since it depends on maturity of both the SSU-only and AMSU-only datasets, merging of the SSU and AMSU at NOAA has been delayed due to the SSU work, but it will be reassumed shortly after the SSU dataset reaches maturity. Meanwhile, RSS developed a weighted combination of AMSU channels 9-14 that matches the vertical weighting functions for SSU channels 1 and the data was put on their website.

- Extend the MSU/AMSU/SSU time series to ATMS: Actual merging with ATMS has not started yet since the ATMS observations are still short. Matching algorithms between AMSU and ATMS for consistent scanning geometries have been investigated at NOAA (Zou and Weng et al. 2014). The algorithm will be used for investigating inter-satellite biases between AMSU and ATMS which will be a basis for future merging between the different instrument observations.
- Lower-tropospheric temperature: NOAA developed AMSU-only channel 4 temperature time series which measures the layer mean temperatures of the lower-troposphere. This temperature time series were derived from AMSU-A channel 4 near nadir observations and thus they are not affected by the orbital-decay as in the MSU temperature of lower-troposphere (TLT) when derived from the MSU/AMSU near limb observations. In addition, temperatures derived from near nadir observations contain much smaller noise than the MSU limb-based TLT dataset. RSS is also developing AMSU-A channel 4 temperature product.
- Merged MSU/AMSU temperatures of mid-troposphere, upper-troposphere and lower-stratosphere: NOAA developed version 3.0 of these products which used MSU satellites from TIROS-N through NOAA-14 and AMSU satellites from NOAA-15 though NOAA-18, NASA AQUA, and European MetOp-A. The products used SNO calibrated swath radiances and contained improved diurnal, limb, and channel frequency corrections. They are updated regularly every month for climate change monitoring at NOAA.

RSS is currently developing Version 4.0 of these datasets. The differences from their V3.3 (the current version and is routinely generated) are as follows:

a. All data is sourced from NOAA's CLASS system. (V3.3 and earlier had some MSU data obtained from other sources, and thus not strictly traceable.)
b. Improved satellite height for some of the early MSU satellites.
c. Improved diurnal adjustments. The previously used model-based adjustments are slightly tuned to remove any remaining trends in intersatellite differences.
d. Improved merging techniques. Intersatellite offsets are calculated separately for land and ocean scenes to decrease the effects of errors in the diurnal adjustment on ocean scenes.
e. Their current product is based on all MSU satellites, and AMSU measurements from NOAA-15, NOAA-18, METOP-A, and AQUA. RSS anticipates releasing V4 during the first half of 2015.

UAH is developing version 6.0 of these products for which they have: (a) recharacterized the diurnal cycle by simply calculating the drift of one sensor relative to a non-drifting sensor at the /*grid*/*month*/*local time*/ level (e.g. NOAA-15 vs. AQUA for a.m. orbiters), (b) generated a multi-channel AMSU product that mimics the weighting functions of MSU channels 2 and 4 at the footprint level and (c) generated an AMSU swath result that is spatially consistent (i.e. backward compatible) with the MSU swath.

- Validate/compare layer temperature products against Radiosonde Observation (Upper Air Observation (RAOB), Global Positioning System Radio Occultation (GPSRO), Lidar, Atmospheric Radiation Measurement (ARM), Atmospheric Infrared Sounder (AIRS), and reanalyses etc. as appropriate throughout the development of the temperature time series: Inter-comparison studies for the MSU-like satellite data with other observations were conducted at all three organizations which resulted in multiple peer-reviewed publications such as Powell, et al. (2013, NOAA), Wang and Zou (2013, NOAA), He et al. (2013, NOAA), and Mears (2012, RSS). Details on comparison results can be found from these publications.

For Specific Deliverable #2

- SNO inter-calibrated AMSU-A radiances onboard NOAA-15 through NOAA-18, Metop- A, and NASA Aqua: The work was completed at NOAA and a whole set of SNO inter-calibrated swath radiances for channels 4-11 on 6 AMSU satellites were transitioned to NOAA/NCDC for archiving and operational distribution. The inter-calibration is currently routinely conducted every month which adding the newly inter-calibrated radiances for the month to the existing datasets.
- SNO inter-calibrated AMSU-A/ATMS radiances: The work has not started yet due to funding limit.
- Recalibration/inter-calibration of SSU swath radiances were recently completed by NOAA team (Zou et al. 2014). The recalibration took into account the space view anomalies and removed artificial satellite biases. The recalibrated radiances were put on the NOAA/STAR website which are expected to improve climate reanalyses in the upper stratosphere.

References:

He, W., C. Zou, and H. Chen, 2014: Validation of AMSU-A measurements from two different calibrations in the lower stratosphere using COSMIC radio occultation data. *Chin. Sci. Bull.*, **59**, 1159–1166, doi:10.1007/s11434-014-0125-9.

Mears, C. A., F. J. Wentz, and P. W. Thorne, 2012: Assessing the value of microwave sounding unit-radiosonde comparisons in ascertaining errors in climate data records of tropospheric temperatures. *J. Geophys. Res. Atmos.*, **117**, D19103, doi:10.1029/2012JD017710.

Powell, A. M. Jr., J. Xu, C.-Z. Zou, and L. Zhao, 2013: Stratospheric and tropospheric SSU/MSU temperature trends and compared to reanalyses and IPCC CMIP5 simulations in 1979–2005. *Atmos. Chem. Phys. Discuss.*, **13**, 3957–3992, doi:10.5194/acpd-13-3957-2013.

Thompson, D. W. J., D. J. Seidel, W. J. Randel, C.-Z. Zou, A. H. Butler, R. Lin, C. Long, C. Mears, and A. Osso, 2012: The mystery of recent stratospheric temperature trends. *Nature*, **491**, 692–697, doi:10.1038/nature11579.

Wang, L, and C.-Z. Zou, 2013: Intercomparison of SSU temperature data records with Lidar, GPS RO, and MLS observations. *J. Geophy. Res. Atmos.*,**118**, 1747–1759, doi:10.1002/jgrd.50162.

Wang, W., and C.-Z. Zou, 2014: AMSU-A-only atmospheric temperature data records from the lower troposphere to the top of the stratosphere. *J. Atmos. Oceanic Technol.*, **31**, 808–825, doi:10.1175/JTECH-D-13-00134.1.

Zou, C.-Z., H. Qian, W. Wang, L. Wang, and C. Long, 2014: Recalibration and merging of SSU observations for stratospheric temperature trend studies. *J. Geophys. Res. Atmos.*, **119**, 13180–13205, doi:10.1002/2014JD021603.

Zou, X., F. Weng, Xiaolei Zou, Fuzhong Weng, and H. Yang, 2014: Connecting the time series of microwave sounding observations from AMSU to ATMS for long-term monitoring of climate. *J. Atmos. Oceanic Technol.*, **31**, 2206–2222, doi:10.1175/JTECH-D-13-00232.

5.3.6.2 GCOS/CEOS Action A21; SS: A.3.1

Action: Ensure the continuity of the constellation of GNSS RO satellites.
Who: Space agencies.
Time-Frame: Ongoing; replacement for current COSMIC constellation needs to be approved urgently to avoid or minimize a data gap.
Performance Indicator: Volume of data available and percentage of data exchanged.
Annual Cost Implications: 10-30M US$ (Mainly by Annex-I Parties).

2015 Update

U.S. agencies and Taiwan have decided to move forward with a follow-on RO mission (called FORMOSAT-7/COSMIC-2) that will launch six satellites into low-inclination orbits in late 2015, and another six satellites into high-inclination orbits in early 2018. U.S. agencies, lead by the National Oceanic and Atmospheric Administration (NOAA) are now actively partnering with Taiwan's National Space Organization (NSPO) to execute the COSMIC-2 program. The Global Navigation Satellite System (GNSS) RO payload, named TGRS for TriG (Tri-GNSS) GNSS Radio-occultation System, is being developed by NASA's Jet Propulsion Laboratory (JPL) and will be capable of tracking up to 12,000 high-quality profiles per day after both constellations are fully deployed.

5.3.7.1 GCOS/CEOS Action A23; SS: A.6. to A.6.6 (cloud amount, cloud top pressure, cloud top temperature, cloud optical depth, cloud water path, and cloud effective particle radius)

Action: Continue the climate data record of visible and infrared radiances, *e.g.,* from the International Satellite Cloud Climatology Project, and include additional data streams as they become available; pursue reprocessing as a continuous activity taking into account lessons learnt from preceding research.
Who: Space agencies, for processing.
Time-Frame: Continuous.
Performance Indicator: Long-term availability of global homogeneous data at high frequency.
Annual Cost Implications: 10-30M US$ (for generation of datasets and products) (Mainly by Annex-I Parties).

2015 Update

- GSICS is providing operationally re-calibrated radiances of the infra-red (IR) and water-vapour (WV) channels of the geostationary satellites operated by the different space-agencies (NOAA, EUMETSAT, CNES, JMA, KMA, CMA, ...). Currently these re-calibrations are only provided for the near-real-time observations. The re-calibration is performed against infrared sounding instruments as a reference. The methods developed within GSICS serve as baseline for developing re-calibration method for SCOPE-CM. The target accuracy of the re-calibrated IR/WV brightness temperatures is 0.5 K.
- GSICS is developing methods to re-calibrate radiances from the visible (VIS) and near-infrared (NIR) channels. GSICS is assessing several re-calibration methods, such as the use of Deep Convective Clouds, Desert Targets, and Moon observations. Moreover, GSICS evaluates Simultaneous Nadir Overpass calibration methods using SCIAMACHY spectra or MODIS radiances. Contrary to the IR/WV methods there is not a single best method for the VIS/NIR re-calibration, making it necessary to combine methods. At first instance these re-calibrations are only provided for the near-real-time observations. The methods developed within GSICS serve as baseline for developing re-calibration method for SCOPE-CM. The target accuracy and precision of the re-calibrated VIS/NIR radiances are 2–3%.
- The SCOPE-CM Inter-calibration of imager observations from time-series of geostationary satellites (IOGEO) project aims to generate a Fundamental Climate Data Record (FCDR) calibrated and quality-controlled geostationary sensor data (~1980 – date). The FCDR will contain VIS, IR, and WV channels of geostationary satellites. It is proposed to utilise the inter-calibration methods developed by GSICS to tie existing time series of satellite data to the best reference available in space. The calibration accuracy and precision will be evaluated by comparing re-calibrated radiances of the different geostationary satellites in overlap regions. The initial aim of this SCOPE-CM activity is that each participating space agencies (EUMETSAT, NOAA, JMA, CMA, IMD) provides FCDRs for their geostationary satellites

at the native instrument resolution. The final aim is to provide a re-gridded (0.05x0.05 degrees) combined global (-70 to 70 degrees) data record (1982–date) at hourly resolution of inter-calibrated radiances including all participating geostationary satellites. Current status is that the participating space agencies are re-calibrating the IR and WV channels of their geostationary instruments. Next year, comparisons of re-calibrated radiances will be made in overlap regions. The re-calibration of the VIS and NIR channels is planned to start in 2016/2017.

- The SCOPE-CM ISCCP project:
  - Reprocessing and stewardship of the ISCCP H-Series production is underway. The major activities thus far have focused on running and properly testing the ISCCP H-series code package. Our QC activities currently use an automated QC procedure combined with visual inspections of GAC and B1U data to eliminate corrupt data from production.
  - Test production of the base period (1983-2009) has begun and HGM products for years 2009-2007 are currently being evaluated via visual inspection and statistical analysis
  - A sample of H-Series data products for 2007 have been distributed to various users/partners within the scientific community. The purpose of this activity is to solicit external feedback on the ISCCP H-Series products and to alert users of its upcoming availability.
  - Updates to the code package continue to be delivered by the PI to fix minor bugs in the code and production
  - Metadata is receiving updates to make all the H-Series products self-describing and to meet CF standards
  - Ancillary products are also receiving minor updates for final production of ISCCP H-Series v01r00 product release.
  - A new website has also been developed and recently launched through NCEI to alert users of the H-Series products and the changes they can expect. The website can be accessed using the following link, http://www.ncdc.noaa.gov/isccp
- The ESA Cloud CCI project:

  Cloud_cci is producing two global long time series of the full suite of GCOS cloud parameters (plus additionally: cloud albedo and emissivity and per pixel uncertainty estimates) from two different optimal estimation retrieval approaches:
  - ATSR2-AATSR-MODIS-AVHRR product covering 33 years, from 1982 to 2014.
  - AATSR-MERIS synergy product covering 2002-2012. Although shorter, this second product makes novel use of the MERIS O2A band to provide a better characterisation of cloud-top height.

  The development of these cloud products is led by CM-SAF leader DWD, and is embedded within the international GEWEX Cloud Assessment and EUMETSAT's Cloud Retrieval Evaluation Workshop (CREW) activities. Additional efforts to support users, such as integration of CCI cloud products in the CFMIP Observation Simulator Package (COSP) are in progress.

  An FCDR consisting of intercalibrated AVHRR radiance data is also developed in collaboration with GSICS, SCOPE-CM and SST_cci.

  See: http://www.esa-cloud-cci.org

References:

Bojanowski, J., R. Stöckli, A. Tetzlaff, and H. Kunz, 2014: The impact of time sifference between satellite overpass and ground observation on cloud cover performance statistics. *Remote Sens*., **6**, 12866–12884, doi:10.3390/rs61212866.

Carbajal Henken, C. K., R. Lindstrot, R. Preusker, and J. Fischer, 2014: FAME-C: Cloud property retrieval using synergistic AATSR and MERIS observations. *Atmos. Meas. Tech. Disc*., **7**, 4909–4947, doi:10.5194/amtd-7-4909-2014.

Hollmann, R., and Coauthors, 2013: The ESA Climate Change Initiative: Satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc*., **94**, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Hollstein, A., J. Fischer, C. Carbajal Henken, and R. Preusker, 2014: Bayesian cloud detection for MERIS, AATSR, and their combination. *Atmos. Meas. Tech. Disc*., **7**, 11045–11085, doi:10.5194/amtd-7-11045-2014.

Karlsson, K.-G., and E. Johansson, 2014: Multi-sensor calibration studies of AVHRR-heritage channel radiances using the simultaneous nadir observation approach. *Remote Sens*., **6**, 1845–1862, doi:10.3390/rs6031845.

Meirink, J. F., R. A. Roebeling, and P. Stammes, 2013: Inter-calibration of polar imager solar channels using SEVIRI. *Atmos. Meas. Tech*., **6**, 2495–2508, doi:10.5194/amt-6-2495-2013.

Stengel, M., and Coauthors, 2014: The Clouds Climate Change Initiative: The assessment of state of the art cloud property retrieval systems applied to AVHRR heritage measurements. *Remote Sens. Environ*..**162**, 363–379.

5.3.7.2 GCOS/CEOS Action A24; SS: A.6.1 to A.6.6 (cloud amount, cloud top pressure, cloud top temperature, cloud optical depth, cloud water path, and cloud effective particle radius)

Action: Research to improve observations of the three-dimensional spatial and temporal distribution of cloud properties.
Who: Parties' national research and space agencies, in cooperation with the WCRP.
Time-Frame: Continuous.
Performance Indicator: New cloud products.
Annual Cost Implications: 30-100M US$ (Mainly by Annex-I Parties).

2015 Update

Developments on the latest status of research on cloud parameter retrievals are presented and discussed at the Workshops of the CGMS International Clouds Working Group. A noticeable finding of the 4th Cloud Retrieval Evaluation Workshop (March 2014, Grainau, Germany) was the increased number of research groups that now implement optimal estimation methods in their operational retrievals. In addition, some research groups have started to combine observations from both passive and active instruments. While the active sensors provide information for only a very small portion of the imager swath, these observations are critical for improving global cloud parameter retrievals. Moreover, the preliminary results presented on the assessments of error estimates produced by some of the retrieval schemes were an important step towards quantifying these estimates in a more systematic manner. These assessments reveal that error estimates compare reasonably well in multiple algorithm ensembles or against the true uncertainty between retrieved and observed cloud parameters. Finally, the evaluation of aggregation methods and filtering rules revealed that the manner of aggregating or filtering level-2 data creates systematic differences in level-3 products that tend to vary regionally depending on climate regions and/or surface conditions. Although the differences are smaller than those between level-2 retrievals they are not negligible.

The main recommendations of the workshop towards future cloud retrieval research are:

- Improve cloud models used in retrievals to more accurately reflect reality, in particular ice crystal models, vertical in-homogeneity, and multiple layers;
- Explore the potential of combining different types of observations in level-2 cloud retrievals methods;
- Explore the definition of a set of essential filtering rules in level-3 aggregation methods for different cloud parameters;
- Work toward the characterisation of uncertainties in level-2 and level-3 products;
- Explore production of multi-algorithm ensembles to assess uncertainty/sensitivity;
- Explore the production of long-term datasets aimed at stability and accurate assessment of product strengths and weaknesses;
- Use common ancillary data and validation procedures for level-2 and level-3 data;
- Establish sub-working groups to make progress on a variety of outstanding issues, for example multi-layered clouds, severe weather applications, and aggregation methods.

5.3.8.1 GCOS/CEOS Action A25; SS: A.7.2 (solar irradiance) and A.7.1 (Earth radiation budget)

Action: Ensure continuation of Earth Radiation Budget observations, with at least one dedicated satellite mission operating at any one time.
Who: Space agencies.
Time-Frame: Ongoing.
Performance Indicator: Long-term data availability at archives.
Annual Cost Implications: 30-100M US$ (Mainly by Annex-I Parties).

2015 Update

The Total Solar Irradiance Calibration Transfer Experiment (TCTE) measures total solar irradiance (TSI), or the total light coming from the Sun at all wavelengths, in order to monitor changes in the incident sunlight at the top of Earth’s atmosphere. The mission mitigates a potential and likely upcoming gap in an otherwise continuous 34-year climate data record following the loss of the NASA Glory mission in 2011. TCTE was successfully launched on November 19, 2013.

Planned: ISS/TSIS with launch in 2017 and continued follow-on missions (from TSIS Performance Requirements)

TSI accuracy 0.01% (0.14 W/m^2) and stability 0.01%/decade (0.14 W/m^2/decade)

SSI accuracy 0.2% and Stability 0.5%/decade for wavelengths <400 nm and 0.1%/decade at wavelengths >400nm

Solar irradiance:

In the frame of CEOS WGCV the solar irradiance spectrum is under reevaluation since 2014 in cooperation between the CEOS WGCv subgroups for Atmospheric Composition (ACSG) and Infrared and Visible Optical Sensors (IVOS). The activity aims to identify the most suitable solar irradiance spectrum in terms of retrieval, calibration, and validation.

Activity updates on solar irradiance measurements:

- ESA's SoHO/VIRGO (TSI) functioning since 1996
- NASA's ACRIMSat/ACRIM3 (TSI) ceased operations in Nov. 2013
- NASA's SORCE/TIM (TSI) continuing since 2003 and achieving target requirements above
- NASA's SORCE/SIM (SSI) continuing since 2003 but not achieving target requirements above
- CNES Picard/PREMOS (TSI) 2010-2014 achieved accuracy target requirements above
- NOAA's STP-Sat3/TCTE/TIM (TSI) launched Nov. 2013 and achieving target requirements above
- NORSAT1/CLARA (TSI) planned for 2016 launch
- NOAA's ISS/TSIS (TSI & SSI) planned for 2017 launch to achieve target and exceed planned requirements given in table above

Earth radiation budget:

CERES FM6 will fly on JPSS-1 in the 2016 timeframe

Broadband Radiometer (BBR) is scheduled to fly on EarthCARE in late 2015.

Responsibility for continuity of Earth radiation observations in the United States has been transferred back to NASA from NOAA. NASA is currently developing the next generation Radiation Budget Instrument (RBI) and it will fly on JPSS-2 in the 2021 timeframe.

References:

Doelling, D. R., N. G. Loeb, D. F. Keyes, M. L. Nordeen, D. Morstad, C. Nguyen, and M. Sun, 2013: Geostationary enhanced temporal interpolation for CERES flux products. *J. Atmos. Oceanic Tech.*, **30**, 1072–1090. doi:10.1175/JTECH-D-12-00136.1

Kato, S., N. G. Loeb, F. G. Rose, D. R. Doelling, D. A. Rutan, T. E. Caldwell, L. Yu, and R. Weller, 2013: Surface irradiances consistent with CERES-derived top-of-atmosphere shortwave and longwave irradiances. *J. Climate*, **26**, 2719–2740, doi:10.1175/JCLI-D-12-00436.1.

Kato, S., N. G. Loeb, D. A. Rutan, F. G. Rose, S. Sun-Mack, W. F. Miller, and Y. Chen, 2012: Uncertainty estimate of surface irradiances computed with MODIS-, CALIPSO-, and CloudSat-derived cloud and aerosol properties. *Surveys Geophys.*, **33**, 395–412, doi:10.1007/s10712-012-9179-x.

Loeb, N. G., D. A. Rutan, S. Kato, and W. Wang, 2014: Observing interannual variations in Hadley circulation atmospheric diabatic heating and circulation strength. *J. Climate*, **27**, 4139–4158, doi:10.1175/JCLI-D-13-00656.1

Loeb, N. G., S. Kato, W. Y. Su, T. M. Wong, F. G. Rose, D. R. Doelling, J. R. Norris, and X. L. Huang, 2012: Advances in understanding top-of-atmosphere radiation variability from satellite observations. *Surveys Geophys*, **33**, 359–385, doi:10.1007/s10712-012-9175-1.

Rutan, D. A., S. Kato, D. R. Doelling, F. G. Rose, C. Nguyen, T. Caldwell, and N. G. Loeb, 2014: CERES Synoptic product: Methodology and validation of surface radiant flux. *J. Atmos. Oceanic Tech.*, in press, doi:10.1175/JTECH-D-14-00165.1

5.3.9.1 GCOS/CEOS Action A26; SS: A.9.3 (ozone), A.5.2 (water vapour), A.8.1 (CO_2 and CH_4)

Action: Establish long-term limb-scanning satellite measurement of profiles of water vapour, ozone and other important species from the UT/LS up to 50 km.
Who: Space agencies, in conjunction with WMO GAW.
Time-Frame: Ongoing, with urgency in initial planning to minimize data gap.
Performance Indicator: Continuity of UT/LS and upper stratospheric data records.
Annual Cost Implications: 100-300M US$ (including mission costs) (Mainly by Annex-I Parties).

2015 Update

The Canadian Space Agency approved the continuation of the SCISAT mission through the end of 2015. The atmospheric chemistry experiment (ACE) Fourier transform infrared spectrometer is unique in its ability to make measurements of upper atmosphere chemistry in the trace gases responsible for ozone depletion. A complete review of this experiment can be found at the following website http://www.ace.uwaterloo.ca/index.html

Limb Sounding Mission Gap

Participants in the CEOS Atmospheric Chemistry Virtual Constellation meeting of 2014 recognize the significance of the looming gap in limb sounding data. Following the demise of the currently operating but aging instruments:

- MLS on Aura (microwave emission),
- SMR (microwave emission) on Odin,
- OSIRIS (limb scatter UV-Vis-NIR) on Odin,
- ACE-FTS (solar occultation IR) on SCISAT, and
- ACE-MAESTRO (solar occultation UV-Vis-NIR) on SCISAT,

the only limb sounding instruments will be:

- OMPS Limb Profiler on Suomi-NPP (limb scatter UV-Vis-NIR),
- SAGE-III/ISS (solar occultation & limb scatter UV-Vis-NIR, planned for 2016),
- OMPS Limb Profiler on JPSS-2 (limb scatter UV-Vis-NIR, planned for ~2021).

Specific Deliverable #2

Maximize use of existing sensors and develop a collaborative framework to advocate and facilitate near-term calibration/validation activities and other coordinated science team planning for near-term space-based missions with limb sounding capability (e.g., to include, but not limited to, Stratospheric Aerosol and Gas Experiment (SAGE) III-ISS and Sentinel 5-Precursor) to maximize scientific output.

5.3.9.2 GCOS/CEOS Action A27; A.11.1

Action: Establish a network of ground stations (MAXDOAS, lidar, FTIR) capable of validating satellite remote sensing of the troposphere.
Who: Space agencies, working with existing networks and environmental protection agencies.
Time-Frame: Urgent.
Performance Indicator: Availability of comprehensive validation reports and near real-time monitoring based on the data from the network.
Annual Cost Implications: 10-30M US$ (30% in non-Annex-I Parties).

2015 Update

ESA is extending its R&D activities for DOAS and Max-DOAS in cooperation with NDACC and CEOS WGCV subgroup Atmospheric Composition. Updated information on in situ networks can be found at the global atmospheric watch website: http://www.wmo.int/pages/prog/arep/gaw/gaw_home_en.html.

5.3.10.1 GCOS/CEOS Action A28; SS A.8.1

Action: Maintain and enhance the WMO GAW Global Atmospheric CO2 and CH4 Monitoring Networks as major contributions to the GCOS Comprehensive Networks for CO2 and CH4.
Who: Parties' national services, research agencies, and space agencies, under the guidance of WMO GAW and its Scientific Advisory Group for Greenhouse Gases, in cooperation with the AOPC.
Time-Frame: Ongoing.
Performance Indicator: Dataflow to archive and analyses centres.
Annual Cost Implications: 10-30M US$ (50% in non-Annex-I Parties).

2015 Update

ESA, in cooperation with CEOS WGCV subgroup Atmospheric Composition, NDACC, and TCOON, will support a 2-year field intercomparison of the different type of FTIR instruments used for GHG satellite validation. In addition, an aircraft-based measurement system for GHG is set up in cooperation with University of Bremen. Updated information on in situ networks can be found at the global atmospheric watch website: http://www.wmo.int/pages/prog/arep/gaw/gaw_home_en.html

5.3.10.2 GCOS/CEOS Action A29; SS A.8.1

Action: Assess the value of the data provided by current space-based measurements of CO2 and CH4, and develop and implement proposals for follow-on missions accordingly.
Who: Parties' research institutions and space agencies.
Time-Frame: Urgent, to minimise data gap following GOSAT.
Performance Indicator: Assessment and proposal documents; approval of consequent missions.
Annual Cost Implications: 1-10M US$ initially, increasing with implementation (10% in non-Annex-I Parties).

2015 Update

CEOS, as the primary international forum for coordination of space-based Earth observations, recently published a response to the Group on Earth Observation's (GEO's) Carbon Observation Strategy: the CEOS Strategy for Carbon Observations from Space. The CEOS Strategy details the adequacy of past, present, and planned satellite measurements of carbon in the land, oceans and inland waters, and atmosphere domains to support GEO. Specifically, it identifies important actions CEOS and its Agencies must take to better coordinate existing and future capabilities, as well as challenges that require additional resources and/or mandates beyond the present capacity of CEOS and its member Agencies. The report can be found here: http://ceos.org/document_management/Publications/WGClimate_CEOS-Strategy-for-Carbon-Observations-from-Space_Apr2014.pdf. Because the CEOS Carbon Task Force had been installed as an ad hoc team, the resulting tasks from the action items of the report are now coordinated by the CEOS SIT team. The Carbon Task Force has been closed with fulfillment of its work plan.

- GHG_cci has developed and tested multiple algorithms to improve CO_2 and CH_4 retrieval accuracies and coverage
    - Core products: Column average CO2 and CH4 from SCIAMACHY (2002-2012) and TANSO (2009-2014).
    - Extra column and profile products providing additional modelling constraints, but which have reduced sensitivity to boundary layer CO2 and CH4 concentration are provided from MIPAS, SCIAMACHY, AIRS, ACE-FTS, and IASI.

  Additionally, multi-mission ensemble products have been prototyped for CO_2. Trials of prototype retrievals for new instruments will be included as part of the project depending on launch dates: OCO-2, TanSat, Sentinel-5P, Merlin, GOSAT-2.

  All developments are taking place in close collaboration with the NASA-ACOS team and the GOSAT teams at NIES and JAXA.

  See: http://www.esa-ghg-cci.org

References:

Alexe, M., and Coauthors, 2015: Inverse modelling of CH4 emissions for 2010–2011 using different satellite retrieval products from GOSAT and SCIAMACHY. *Atmos. Chem. Phys.*, **15**, 113–133, doi:10.5194/acp-15-113-2015.

Basu, S., and Coauthors, 2013: Global CO2 fluxes estimated from GOSAT retrievals of total column CO2. *Atmos. Chem. Phys.*, **13**, 8695–8717, doi:10.5194/acp-13-8695-2013.

Basu, S., and Coauthors, 2014: The seasonal variation of the CO 2 flux over Tropical Asia estimated from GOSAT, CONTRAIL, and IASI. *Geophys. Res. Lett.*, **41**, 1809–1815, doi:10.1002/2013GL059105.

Buchwitz, M., and Coauthors, 2013: Carbon Monitoring Satellite (CarbonSat): assessment of scattering related atmospheric CO2 and CH4 retrieval errors and first results on implications for inferring city CO2 emissions. *Atmos. Meas. Tech. Disc.*, **6**, 4769–4850, doi:10.5194/amtd-6-4769-2013.

Buchwitz, M., and Coauthors, 2013: The Greenhouse Gas Climate Change Initiative (GHG-CCI): Comparison and quality assessment of near-surface-sensitive satellite-derived CO2 and CH4 global data sets. *Remote Sens. Environ.*. 162, 344–362, doi:10.1016/j.rse.2013.04.024.

Butz, A., and Coauthors, 2011: Toward accurate CO 2 and CH 4 observations from GOSAT. *Geophys. Res. Lett.*, **38**, L14812, doi:10.1029/2011GL047888.

Chevallier, F., and C. W. O'Dell, 2013: Error statistics of Bayesian CO 2 flux inversion schemes as seen from GOSAT. *Geophys. Res. Lett.*, **40**, 1252–1256, doi:10.1002/grl.50228.

Chevallier, F., P. I. Palmer, L. Feng, H. Boesch, C. W. O'Dell, and P. Bousquet, 2014: Toward robust and consistent regional CO 2 flux estimates from in situ and spaceborne measurements of atmospheric CO 2. *Geophys. Res. Lett.*, **41**, 1065–1070, doi:10.1002/2013GL058772.

Cressot, C., and Coauthors, 2013: On the consistency between global and regional methane emissions inferred from SCIAMACHY, TANSO-FTS, IASI and surface measurements. *Atmos. Chem. Phys. Disc.*, **13**, 8023–8064, doi:10.5194/acpd-13-8023-2013.

Crevoisier, C., and Coauthors, 2013: The 2007–2011 evolution of tropical methane in the mid-troposphere as seen from space by MetOp-A/IASI. *Atmos. Chem. Phys.*, **13**, 4279–4289, doi:10.5194/acp-13-4279-2013.

Dils, B., and Coauthors, 2013: The Greenhouse Gas Climate Change Initiative (GHG-CCI): Comparative validation of GHG-CCI SCIAMACHY/ENVISAT and TANSO-FTS/GOSAT CO2 and CH4 retrieval algorithm products with measurements from the TCCON network. *Atmos. Meas. Tech. Disc.*, **6**, 8679–8741, doi:10.5194/amtd-6-8679-2013.

Fraser, A., and Coauthors, 2012: Estimating regional methane surface fluxes: The relative importance of surface and GOSAT mole fraction measurements. *Atmos. Chem. Phys. Disc.*, **12**, 30989–31030, doi:10.5194/acpd-12-30989-2012.

Fraser, A., and Coauthors, 2014: Estimating regional fluxes of CO2 and CH4 using space-borne observations of XCH4 : XCO2. *Atmos. Chem. Phys. Disc.*, **14**, 15867–15894, doi:10.5194/acpd-14-15867-2014.

Guerlet, S., and Coauthors, 2013: Reduced carbon uptake during the 2010 Northern Hemisphere summer from GOSAT. *Geophys. Res. Lett.*, **40**, 2378–2383, doi:10.1002/grl.50402.

Guerlet, S., and Coauthors, 2013: Impact of aerosol and thin cirrus on retrieving and validating XCO 2 from GOSAT shortwave infrared measurements. *J. Geophys. Res. Atmos.*, **118**, 4887–4905, doi:10.1002/jgrd.50332.

Heymann, J., and Coauthors, 2012: SCIAMACHY WFM-DOAS XCO2: Reduction of scattering related errors. *Atmos. Meas. Tech.*, **5**, 2375–2390, doi:10.5194/amt-5-2375-2012.

Heymann, J., and Coauthors, 2012: SCIAMACHY WFM-DOAS XCO2: Comparison with CarbonTracker XCO2 focusing on aerosols and thin clouds. *Atmos. Meas. Tech.*, **5**, 1935–1952, doi:10.5194/amt-5-1935-2012.

Hollmann, R., and Coauthors, 2013: The ESA Climate Change Initiative: Satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, **94**, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Monteil, G., and Coauthors, 2013: Comparison of CH 4 inversions based on 15 months of GOSAT and SCIAMACHY observations. *J. Geophys. Res. Atmos.*, **118**, 11,807–11,823, doi:10.1002/2013JD019760.

Noël, S., K. Bramstedt, A. Rozanov, H. Bovensmann, and J. P. Burrows, 2011: Stratospheric methane profiles from SCIAMACHY solar occultation measurements derived with onion peeling DOAS. *Atmos. Meas. Tech.*, **4**, 2567–2577, doi:10.5194/amt-4-2567-2011.

Parker, R., and Coauthors, 2011: Methane observations from the Greenhouse Gases Observing SATellite: Comparison to ground-based TCCON data and model calculations. *Geophys. Res. Lett.*, **38**, L15807, doi:10.1029/2011GL047871.

Reuter, M., and Coauthors, 2013: A joint effort to deliver satellite retrieved atmospheric CO2 concentrations for surface flux inversions: the ensemble median algorithm EMMA. *Atmos. Chem. Phys.*, **13**, 1771–1780, doi:10.5194/acp-13-1771-2013.

Reuter, M., and Coauthors, 2011: Retrieval of atmospheric CO 2 with enhanced accuracy and precision from SCIAMACHY: Validation with FTS measurements and comparison with model results. *J. Geophys. Res. Atmos.*, **116**, D04301, doi:10.1029/2010JD015047.

Reuter, M., and Coauthors, 2012: On the potential of the 2041–2047nm spectral region for remote sensing of atmospheric CO2 isotopologues. *J. Quant. Spectrosc. Rad. Trans.*, **113**, 2009–2017, doi:10.1016/j.jqsrt.2012.07.013.

Reuter, M., Buchwitz, M., Hilboll, A., Richter, A., Schneising, O., Hilker, M., … Burrows, J. P. (2014). Decreasing emissions of NOx relative to CO2 in East Asia inferred from satellite observations. *Nature Geoscience*, advance on(11), 792–795. doi:10.1038/ngeo2257

Reuter, M., and Coauthors, 2014: Satellite-inferred European carbon sink larger than expected. *Atmos. Chem. Phys.*, **14**, 13739–13753, doi:10.5194/acp-14-13739-2014.

Reuter, M., and Coauthors, 2012: A simple empirical model estimating atmospheric CO2 background concentrations. *Atmos. Meas. Tech.*, **5**, 1349–1357, doi:10.5194/amt-5-1349-2012.

Ross, A. N., M. J. Wooster, H. Boesch, and R. Parker, 2013: First satellite measurements of carbon dioxide and methane emission ratios in wildfire plumes. *Geophys. Res. Lett.*, **40**, 4098–4102, doi:10.1002/grl.50733.

Schepers, D., and Coauthors, 2012: Methane retrievals from Greenhouse Gases Observing Satellite (GOSAT) shortwave infrared measurements: Performance comparison of proxy and physics retrieval algorithms. *J. Geophys. Res. Atmos.*, **117**, D10307, doi:10.1029/2012JD017549.

Schneising, O., M. Buchwitz, M. Reuter, J. Heymann, H. Bovensmann, and J. P. Burrows, 2011: Long-term analysis of carbon dioxide and methane column-averaged mole fractions retrieved from SCIAMACHY. *Atmos. Chem. Phys.*, **11**, 2863–2880, doi:10.5194/acp-11-2863-2011.

Schneising, O., J. P. Burrows, R. R. Dickerson, M. Buchwitz, M. Reuter, and H. Bovensmann, 2014: Remote sensing of fugitive methane emissions from oil and gas production in North American tight geologic formations. *Earth's Future*, **2**, 548–558, doi:10.1002/2014EF000265.

Schneising, O., J. Heymann, M. Buchwitz, M. Reuter, H. Bovensmann, and J. P. Burrows, 2013: Anthropogenic carbon dioxide source areas observed from space: Assessment of regional enhancements and trends. *Atmos. Chem. Phys.*, **13**, 2445–2454, doi:10.5194/acp-13-2445-2013.

Schneising, O., M. Reuter, M. Buchwitz, J. Heymann, H. Bovensmann, and J. P. Burrows, 2013: Terrestrial carbon sink observed from space: Variation of growth rates and seasonal cycle amplitudes in response to interannual surface temperature variability. *Atmos. Chem. Phys. Disc.*, **13**, 22733–22755, doi:10.5194/acpd-13-22733-2013.

Sussmann, R., F. Forster, M. Rettinger, and P. Bousquet, 2012: Renewed methane increase for five years (2007–2011) observed by solar FTIR spectrometry. *Atmos. Chem. Phys.*, **12**, 4885–4891, doi:10.5194/acp-12-4885-2012.

Sussmann, R., and Coauthors, 2013: First intercalibration of column-averaged methane from the Total Carbon Column Observing Network and the Network for the Detection of Atmospheric Composition Change. *Atmos. Meas. Tech.*, **6**, 397–418, doi:10.5194/amt-6-397-2013.

Wecht, K. J., and Coauthors, 2014: Spatially resolving methane emissions in California: Constraints from the CalNex aircraft campaign and from present (GOSAT, TES) and future (TROPOMI, geostationary) satellite observations. *Atmos. Chem. Phys. Disc.*, **14**, 4119–4148, doi:10.5194/acpd-14-4119-2014.

5.3.11.1 GCOS/CEOS Action 32; SS: A.9.1 (total column ozone), A..9.2 (tropospheric ozone), and A.9.3 (ozone profiles)

Action: Continue production of satellite ozone data records (column, tropospheric ozone and ozone profiles) suitable for studies of interannual variability and trend analysis. Reconcile residual differences between ozone datasets produced by different satellite systems.
Who: Space agencies.
Time-Frame: Ongoing.
Performance Indicator: Statistics on availability and quality of data.
Annual Cost Implications: 10-30M US$ (Mainly by Annex-I Parties).

2015 Update

1. Total Ozone
1.a. NOAA Instruments on Polar Orbiters at 13:30.

The last remaining SBUV/2 on NOAA-19 POES is working well but its orbit has drifted past 2:00 PM Equator- crossing time and is headed even later. It has had some minor problems with one of the reflectivity channles but is continuing the long-term SBUV/2 total ozone record.

The OMPS Nadir Mapper on S-NPP is working very well. It is a stable instrument and on-board monitoring is providing calibration characterization that is expected to meet its stability requirement of 1% over the lifetime of the mission. We have added procedures to make stray light and wavelength scale correction using both on- ground characterization and in-orbit consistency checks to generate accurate level 1 products with high signal to noise ratios. Comparisons of reprocessed data sets for the first three years (provide by the NASA Ozone PEATE) show a total ozone record that that meets the 2% accuracy target. Its horizontal resolution is currently 50 KM at nadir and increases with viewing angle. We expect to implement the V8 Total Ozone algorithm in operations (in place of the current algorithm) and make soft calibration adjustments to the Level 1 product at the same time to produce a close to CDR quality operational product within the next year. (Aside: The adaptation of the V8 total ozone algorithm for use with OMPS was supported by an NCDC project.)

The next OMPS Nadir Mapper will be launched on JPSS-1 in 2017. It has passed its pre-shipment review. We expect to increase the horizontal resolution by a factor of three (to ~17 KM at nadir) but maintain the accuracy and stability of the products. This will be followed by a third and final OMPS on JPSS-2.

1.b. Instruments at L-1 and GEO.

The DSCOVR mission (joint NOAA/NASA) will be place at the Lagrange-1 Point and have the EPIC instrument on-board. This ten-channel filter CCD array instrument will make measurements of total ozone over the sunlit face of the Earth. It is scheduled for launch early next year (2015). We plan to use it as a transfer standard for total ozone measurements from low-Earth-orbiting sensors. (I have attached a poster on EPIC and the three instruments in the next section as well as some plans for their use for comparisons and inter-calibration.)

1.c. Instruments on Geostationary platforms

In the 2018-2020 time frame there are plans for at least three hyperspectral atmospheric composition instruments - NASA TEMPO, Korea's GEMS, and ESA's UVN. These instruments will produce good ozone measurements with high spatial and temporal resolution over their targeted areas - North America, Asia, and Europe, respectively. Again comparisons with other satellite measurements will help to provide a stable system of ozone monitoring instruments.

1.d. ESA Instruments on Polar orbiter and NASA OMI.

Ozone_cci has produced long time series of total column from multiple nadir and limb sounding instruments. Per retrieval uncertainty estimates are provided in the products.
16 years (1996-2014) of harmonised total column O_3 records from GOME, SCIAMACHY, GOME-2, and OMI.
Consistency between these new data sets and other ozone products (TOMS, SBUV, OMPS, HALOE, SAGE, MLS, and IASI) has been investigated, as well as between the total column and profile products.
Close interaction has been maintained with CEOS ACC, GCOS, IO3C and WMO Ozone Assessment.
See : http://www.esa-ozone-cci.org.

In mid-2016, the Sentinel 5 Precursor will be launched contributing to total ozone, ozone profiles and tropospheric ozone content. Sentinel 5 on-board Meteosat Third Generation (MTG) is expected to be launched around 2021 providing the continuity from Sentinel 5 P onwards.

2. Ozone Profiles from Nadir Instruments

2.a. NOAA Instruments on Polar Orbiters at 13:30.

The last remaining SBUV/2 on NOAA-19 POES is working well but its orbit has drifted past 2:00 PM Equator-crossing time and is headed even later. It has had some minor problems with one of the reflectivity channels but is continuing the long-term SBUV/2 ozone profile climate data record. This record has been updated with NOAA-19 SBUV/2 products through June 2014.

The OMPS Nadir Profiler on S-NPP is working very well. It is a stable instrument and on-board monitoring is providing calibration characterization that is expected to meet its stability requirement of 2% over the lifetime of the mission. We have added procedures to make stray light and wavelength scale correction using both on-ground characterization and in-orbit consistency checks to generate accurate level 1 products. Comparisons of chasing orbits (opportunistic formation flying that occurs approximately every 12 days) with NOAA-19 SVBUV/2 for the first three years show an ozone profile record that that will meets the 2% long-term stability and 5% accuracy targets. We expect to implement the V8 Ozone Profile algorithm in operations (in place of the current algorithm) and make soft calibration adjustments to the Level 1 product at the same time to produce a close to CDR quality operational product within the next year. (Aside: The adaptation of the V8 ozone profile algorithm for use with OMPS was supported by an NCDC project.) We expect the OMPS NP products to provide excellent continuity of the SBVU/2 record as they have controlled equator crossing times and an onboard system of working and reference diffusers.

The next OMPS Nadir Profiler will be launched on JPSS-1 in 2017. It has passed its pre-shipment review. We expect to increase the horizontal resolution by a factor of five (to ~50 KM at nadir but still restricted to a 250-km nadir swath) but maintain the accuracy and stability of the products. This will be followed by a third and final OMPS on JPSS-2.

2.b. Tropospheric Ozone Residuals.

The SBUV/2 and OMPS ozone profile product can be used to estimate the stratospheric contribution to the column ozone for the full globe by using assimilation or analysis methods. These have been combined with other estimates of total column ozone (e.g., daily maps) to produce estimates for tropospheric ozone by simple subtraction of the stratospheric columns from the total columns. Other more sophisticated methods using cloud slicing and deep convective clouds have also been used to provide long term tropospheric ozone records. The OMPS Nadir Mapper measurements match the quality and information content of the OMI measurements used in those studies, and so it should be able to continue those record.

2.c. Infrared ozone measurements.

The new hypespectral infrared instruments (US AIRS and CrIS, and European IASI) have information on ozone variations in the upper troposphere and lower stratosphere. The operational NOAA products from CrIS include ozone profile estimates. We are making a combined product using the SBUV/2 and OMPS NP Stratospheric information together with this IR information in the lower atmosphere to generate total ozone maps. We are developing a sequential retrieval using the OMPS NP maximum likelihood retrieval as an a priori for the CrIS maximum likelihood retrieval that will combine the complementary information content of the two sets of measurements.

2.d. ESA Instruments on Polar orbiter, NASA OMI and IASI on Metop.

Ozone_cci has produced long time series of ozone vertical profile measurements from multiple nadir sounding instruments. Per retrieval uncertainty estimates are provided in the products.

O_3 profiles from nadir instruments: GOME, SCIAMACHY, GOME-2, OMI and IASI.

Consistency between these new data sets and other ozone products (TOMS, SBUV, OMPS, HALOE, SAGE, MLS, and IASI) has been investigated, as well as between the total column and profile products.

Close interaction has been maintained with CEOS ACC, GCOS, IO3C and WMO Ozone Assessment.

See : http://www.esa-ozone-cci.org.

3. Ozone Profiles from Limb Instruments

3.a. NOAA Instruments on Polar Orbiters at 13:30.

The S-NPP OMPS Limb Profiler is performing well. The NASA OMPS Science Team is creating ozone profile products with 3-km or better vertical resolution down to the tropopause. NOAA has a project to implement this retrieval algorithm operationally. The next planned OMPS Limb Profiler is not expected until JPSS-2. Fortunately, while it is only a five-year mission on paper, the S-NPP spacecraft has fuel and power resources to operate for at least 12 more years, and the OMPS was designed for seven years reliability. This means that it is likely (>70%) that it will continue to function for 12 years as well. The current trending of instrument and detector degradation show manageable changes over that period.

3.b Other US Assets

NASA has plans to place a SAGE III instrument on the International Space Station in 2016. See http://sage.nasa.gov/SAGE3ISS/ . We expect to have good overlap between the measurements from the OMPS LP and the SAGE III. If for some reason the OMPS LP on S-NPP did not last until the launch of the second one on JPSS-2, we could use the ISS SAGE III as a transfer between the two.

3.c. ESA Instruments on Polar orbiter, and National Instruments.

Ozone_cci has produced long time series of ozone vertical profile measurements from multiple nadir sounding instruments. Per retrieval uncertainty estimates are provided in the products.

O_3 profiles from limb sounders: GOMOS, MIPAS, SCIAMACHY, OSIRIS, SMR and ACE/FTS (full-mission, harmonised, single instrument and merged data sets).

Consistency between these new data sets and other ozone products (TOMS, SBUV, OMPS, HALOE, SAGE, MLS, and IASI) has been investigated, as well as between the total column and profile products.

Close interaction has been maintained with CEOS ACC, GCOS, IO3C and WMO Ozone Assessment.

See : http://www.esa-ozone-cci.org.

References:

Adams, C., and Coauthors, 2013: Characterization of Odin-OSIRIS ozone profiles with the SAGE II dataset. *Atmos. Meas. Tech.*, **6**, 1447–1459, doi:10.5194/amt-6-1447-2013.

Adams, C., and Coauthors, 2013: Assessment of Odin-OSIRIS ozone measurements from 2001 to the present using MLS, GOMOS, and ozone sondes. *Atmos. Meas. Tech. Disc.*, **6**, 3819–3857, doi:10.5194/amtd-6-3819-2013.

Aschmann, J., J. P. Burrows, C. Gebhardt, A. Rozanov, R. Hommel, M. Weber, and A. M. Thompson, 2014: On the hiatus in the acceleration of tropical upwelling since the beginning of the 21st century. *Atmos. Chem. Phys.*, **14**, 12803–12814, doi:10.5194/acp-14-12803-2014.

Braesicke, P., O. See Hai, and A. Abu Samah, 2012: Properties of strong off-shore Borneo vortices: A composite analysis of flow pattern and composition as captured by ERA-Interim. *Atmos. Sci. Lett.*, **13**, 128–132, doi:10.1002/asl.372.

Cai, D., M. Dameris, H. Garny, and T. Runde, 2012: Implications of all season Arctic sea-ice anomalies on the stratosphere. *Atmos. Chem. Phys.*, **12**, 11819–11831, doi:10.5194/acp-12-11819-2012.

Chiou, E. W., and Coauthors, 2013: Comparison of profile total ozone from SBUV(v8.6) with GOME-type and ground-based total ozone for 16-yr period (1996 to 2011). *Atmos. Meas. Tech. Disc.*, **6**, 10081–10115, doi:10.5194/amtd-6-10081-2013

Coldewey-Egbers, M., D. G. Loyola R., P. Braesicke, M. Dameris, M. van Roozendael, C. Lerot, and W. Zimmer, 2014: A new health check of the ozone layer at global and regional scales. *Geophys. Res. Lett.*, **41**, 4363–4372, doi:10.1002/2014GL060212.

Dameris, M., and M. P. Baldwin, 2011: Impact of climate change on the stratospheric ozone layer. In *Stratospheric Ozone Depletion and Climate Change*, R. Muller, Ed., Royal Society of Chemistry, pp. 214–252, doi:10.1039/9781849733182.

Dameris, M., and P. Jöckel, 2013: Numerical modeling of climate-chemistry connections: Recent developments and future challenges. *Atmosphere*, **4**, 132–156, doi:10.3390/atmos4020132.

Dameris, M., and D. Loyola, 2012: Recent and future evolution of the stratospheric ozone layer. In *Atmospheric Physics*. Research Topics in Aerospace, E. Schumann, Ed., Springer, pp. 747–761, doi:10.1007/978-3-642-30183-4.

Dameris, M. and D. Loyola, 2011: Chemistry-climate connections – Interaction of physical, dynamical, and chemical processes in Earth atmosphere. In *Climate Change - Geophysical Foundations and Ecological Effects*, J. A. Blanco and H. Kheradmand, Eds., InTech, doi:10.5772/24210

De Laat, A. T. J., and M. van Weele, 2011: The 2010 Antarctic ozone hole: observed reduction in ozone destruction by minor sudden stratospheric warmings. *Scientific Reports*, **1**, 38, doi:10.1038/srep00038.

Ebojie, F., and Coauthors, 2013: Tropospheric column amount of ozone retrieved from SCIAMACHY limb-nadir-matching observations. *Atmos. Meas. Tech. Disc.*, **6**, 7811–7865, doi:10.5194/amtd-6-7811-2013.

Eckert, E., and Coauthors, 2013: Drift-corrected trends and periodic variations in MIPAS IMK/IAA ozone measurements. *Atmos. Chem. Phys. Disc.*, **13**, 17849–17900, doi:10.5194/acpd-13-17849-2013.

Gebhardt, C., and Coauthors, 2013: Stratospheric ozone trends and variability as seen by SCIAMACHY during the last decade. *Atmos. Chem. Phys. Disc.*, **13** , 11269–11313, doi:10.5194/acpd-13-11269-2013.

Hollmann, R., and Coauthors, 2013:. The ESA Climate Change Initiative: Satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, **94**, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Kyrölä, E., and Coauthors, 2013: Combined SAGE II-GOMOS ozone profile data set 1984–2011 and trend analysis of the vertical distribution of ozone. *Atmos. Chem. Phys. Disc.*, **13**, 10661–10700, doi:10.5194/acpd-13-10661-2013.

Laeng, A., and Coauthors, 2014:. Validation of MIPAS IMK/IAA V5R_O3_224 ozone profiles. *Atmos. Meas. Tech.*, **7**, 3971–3987, doi:10.5194/amt-7-3971-2014.

Laeng, A., and Coauthors, 2015: The ozone climate change initiative: Comparison of four Level-2 processors for the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS). *Remote Sens. Environ.*, **162**, 316–343, doi:10.1016/j.rse.2014.12.013.

Lerot, C., and Coauthors, 2013: Homogenized total ozone data records from the European sensors GOME/ERS-2, SCIAMACHY/Envisat and GOME-2/MetOp-A. *J. Geophys. Res. Atmos.*, **119**, 1639–1662, doi:10.1002/2013JD020831.

Loyola, D. G., and M. Coldewey-Egbers, 2012: Multi-sensor data merging with stacked neural networks for the creation of satellite long-term climate data records. *EURASIP J. Adv. Signal Process.*, **2012**, 91, doi:10.1186/1687-6180-2012-91

Mieruch, S., and Coauthors, 2012: Global and long-term comparison of SCIAMACHY limb ozone profiles with correlative satellite data (2002–2008). *Atmos. Meas. Tech.*, **5**, 771–788, doi:10.5194/amt-5-771-2012.

Mijling, B., O. N. E. Tuinder, R. F. van Oss, and R. J. van der A, 2010: Improving ozone profile retrieval from spaceborne UV backscatter spectrometers using convergence behaviour diagnostics. *Atmos. Meas. Tech.*, **3**, 1555–1568, doi:10.5194/amt-3-1555-2010.

Miles, G. M., R. Siddans, B. J. Kerridge, B. G. Latter, and N. A. D. Richards, 2015: Tropospheric ozone and ozone profiles retrieved from GOME-2 and their validation. *Atmos. Meas. Tech.*, **8**, 385–398, doi:10.5194/amt-8-385-2015.

Miyazaki, K., H. J. Eskes, K. Sudo, M. Takigawa, M. van Weele, and K. F. Boersma, 2012: Simultaneous assimilation of satellite NO2, O3, CO, and HNO3 data for the analysis of tropospheric chemical composition and emissions. *Atmos. Chem. Phys.*, **12**, 9545–9579, doi:10.5194/acp-12-9545-2012.

Rahpoe, N., C. von Savigny, M. Weber, A. V. Rozanov, H. Bovensmann, and J. P. Burrows, 2013: Error budget analysis of SCIAMACHY limb ozone profile retrievals using the SCIATRAN model. *Atmos. Meas. Tech. Disc.*, **6**, 4645–4676, doi:10.5194/amtd-6-4645-2013.

Richards, N. A. D., and Coauthors, 2012: Source attribution and radiative impacts of the Mediterranean summertime ozone maximum: a satellite and model perspective. *Atmos. Chem. Phys. Disc.*, **12**, 27219–27254, doi:10.5194/acpd-12-27219-2012.

Sioris, C. E., C. A. McLinden, V. E. Fioletov, C. Adams, J. M. Zawodny, A. E. Bourassa, and D. A. Degenstein, 2013: Trend and variability in ozone in the tropical lower stratosphere over 2.5 solar cycles observed by SAGE II and OSIRIS. *Atmos. Chem. Phys. Disc.*, **13**, 16661–16697, doi:10.5194/acpd-13-16661-2013.

Sofieva, V. F., and Coauthors, 2013: Harmonized dataset of ozone profiles from satellite limb and occultation measurements. *Earth Syst. Sci. Data Disc.*, **6**, 189–222, doi:10.5194/essdd-6-189-2013.

Sofieva, V. F., J. Tamminen, E. Kyrölä, T. Mielonen, P. Veefkind, B. Hassler, and G. E. Bodeker, 2013: A novel tropopause-related climatology of ozone profiles. *Atmos. Chem. Phys. Disc.*, **13**, 21345–21382, doi:10.5194/acpd-13-21345-2013.

Sonkaew, T., C. von Savigny, K.-U. Eichmann, M. Weber, A. Rozanov, H. Bovensmann, and J. P. Burrows, 2011: Chemical ozone loss in Arctic and Antarctic polar winter/spring season derived from SCIAMACHY limb measurements 2002–2009. *Atmos. Chem. Phys. Disc.*, **11**, 6555–6599, doi:10.5194/acpd-11-6555-2011.

Spurr, R., V. Natraj, C. Lerot, M. Van Roozendael, and D. Loyola, 2013: Linearization of the Principal Component Analysis method for radiative transfer acceleration: Application to retrieval algorithms and sensitivity studies. *J. Quant. Spectrosc. Rad. Trans.*, **125**, 1–17, doi:10.1016/j.jqsrt.2013.04.002.

Valks, P., N. Hao, S. Gimeno Garcia, D. Loyola, M. Dameris, P. Jöckel, and A. Delcloo, 2014: Tropical tropospheric ozone column retrieval for GOME-2. *Atmos. Meas. Tech.*, **7**, 2513–2530, doi:10.5194/amt-7-2513-2014.

Van Peet, J. C. A., R. J. van der A, O. N. E. Tuinder, E. Wolfram, J. Salvador, P. F. Levelt, and H. M. Kelder, 2013: Ozone ProfilE Retrieval Algorithm for nadir-looking satellite instruments in the UV-VIS. *Atmos. Meas. Tech. Disc.*, **6**, 9061–9107, doi:10.5194/amtd-6-9061-2013.

Van Roozendael, M., and Coauthors, 2012: Sixteen years of GOME/ERS-2 total ozone data: The new direct-fitting GOME Data Processor (GDP) version 5—Algorithm description. *J. Geophys. Res. Atmos.*, **117**, D03305. doi:10.1029/2011JD016471.

5.3.12.1 GCOS/CEOS Action A33; A.10.1 to A.10.4 (aerosol optical depth, aerosol single scattering albedo, aerosol layer height, and aerosol extinction profiles)

Action: Develop and implement a coordinated strategy to monitor and analyse the distribution of aerosols and aerosol properties. The strategy should address the definition of a GCOS baseline network or networks for *in situ* measurements, assess the needs and capabilities for operational and research satellite missions for the next two decades, and propose arrangements for coordinated mission planning.
Who: Parties' national services, research agencies and space agencies, with guidance from AOPC and in cooperation with WMO GAW and AERONET.
Time-Frame: Ongoing, with definition of baseline *in situ* components and satellite strategy by 2011.
Performance Indicator: Designation of GCOS baseline network(s). Strategy document, followed by implementation of strategy.
Annual Cost Implications: 10-30M US$ (20% in non-Annex-I Parties).

2015 Update

Atmospheric aerosol was identified as an ECV by GCOS (2010) due to its important direct and indirect climate radiative forcing effects. The anthropogenic component of atmospheric aerosol is the most uncertain climate forcing constituent and the sign of its climate forcing is generally opposite to that of greenhouse gases. In the past two decades, significant advance in satellite and surface observations of aerosol optical and distribution properties (optical thickness, single scattering albedo, aerosol layer height, and aerosol extinction profiles) have been achieved due to dedicated aerosol observations from both space and surface.

Dedicated global satellite aerosol observations using multiple-spectral, -angles, and polarization retrieval techniques started in late 1990s and early 2000s from POLDER, SeaWiFS, MODIS, MISR, AATSR, GLI, OMI, etc (King et al., 1999) in order to better quantify aerosol loading (e.g., aerosol optical thickness), size parameter (e.g., aerosol angstrom exponent), aerosol type (e.g., dust and smoke), and absorbing characteristic (e.g., aerosol single scattering). CALIPSO lidar launched in the middle of 2000s on NASA A-Train constellation satellites (Winker et al., 2007) further added information of aerosol vertical distribution, such as aerosol layer height and aerosol extinction profiles. At the same time, GEWEX Global Aerosol Climatology Project (GACP) (Mishchenkoa et al., 2007) and NOAA aerosol climate data record (CDR) project (Zhao et al., 2008) reprocessed historical operational AVHRR satellite observations to generate more than 30-years aerosol climate datasets for aerosol trend detection. Dedicated satellite aerosol observations will continue and extend to next decade from both operational satellite missions (e.g., JPSS, GOES-R, EPS-SG, MTG) and research satellite missions (e.g., EarthCare, Sentinel-4/5, PACE). NOAA CDR Program will incorporate both current and future satellite aerosol observations into its aerosol climate dataset so that the aerosol climate data record will be extended to over 50-years long.

Globally coordinated surface aerosol observations have also been enhanced greatly in recently two decades due to the establishment of AErosol RObotic NETwork (AERONET) program (Holben et al., 1997), which is a federation of ground-based remote sensing aerosol networks established by NASA and PHOTONS (PHOtométrie pour le Traitement Opérationnel de Normalisation Satellitaire) and is greatly expanded by collaborators from national/international agencies, institutes, universities, individual scientists, and partners. The program provides a long-term, continuous and readily accessible public domain database of aerosol optical, microphysical and radiative properties for aerosol research and characterization, validation of satellite retrievals, and synergism with other databases. The network currently contains more than 600 sites over the globe and imposes standardization of instruments, calibration, processing and distribution.

Both global observations and surface measurements dedicated to aerosol will be continued in parallel to next decade so that long term changes and variations of aerosol optical and distribution properties along with aerosol climate radiative forcing can be detected with less uncertainty and high confidence (Li et al., 2009).

References:

GCOS, Implementation plan for the global observing system for climate in support of the UNFCCC (2010 update). GCOS Rep. 138, 186 pp., 2010. [Available online at http://www.wmo.int/pages/prog/gcos/Publications/gcos-138.pdf.]

Holben B. N., T. F. Eck, I. Slutsker, D. Tanre, J. P. Buis, A. Setzer, E. Vermote, J. A. Reagan, Y. Kaufman, T. Nakajima, F. Lavenu, I. Jankowiak, and A. Smirnov, 1998: AERONET - A federated instrument network and data archive for aerosol characterization. *Remote Sens. Environ.*, **66**, 1–16.

Holben, B.N., D. Tanre, A. Smirnov, T.F. Eck, I. Slutsker, N. Abuhassan, W. Newcomb, and J.S. Schafer, 2001: An emerging ground-based aerosol climatology: Aerosol optical depth from AERONET. *J. Geophys. Res.*, **106**(D11), 12067–12097.

King, M. D., Y. J. Kaufman, D. Tanré, and T. Nakajima, 1999: Remote sensing of tropospheric aerosols from space: Past, present, and future. *Bull. Amer. Meteor. Soc.*, **80**, 2229–2259.

Li, Z., T. X.-P. Zhao, R. Kahn, M. Mishchenko, L. Remer, K.-H. Lee, M. Wang, I. Laszlo, T. Nakajima, and H. Maring, 2009: Uncertainties in satellite remote sensing of aerosols and impact on monitoring its long-term trend: a review and perspective. *Ann. Geophys.*, **27**, 2755–2770.

Mishchenkoa, M. I., I. V. Geogdzhayevb, B. Cairnsb, B. E. Carlsona, J. Chowdharyb, A. A. Lacisa, L. Liub, W. B. Rossowa, and L. D. Travis, 2007: Past, present, and future of global aerosol climatologies derived from satellite observations: A perspective. *J. Quant. Spectrosc. Radiative Transfer*, **106**, 325–347.

Winker, D. M., W. H. Hunt, and M. J. McGill, 2007: Initial performance assessment of CALIOP. *Geophys. Res. Lett.*, **34**, L19803, doi:10.1029/2007GL030135.

Zhao, T. X.-P., I. Laszlo, W. Guo, A. Heidinger, C. Cao, A. Jelenak, D. Tarpley, and J. Sullivan, 2008: Study of long-term trend in aerosol optical thickness observed from operational AVHRR satellite instrument. *J. Geophys. Res.*, **113**, D07201, doi:10.1029/2007JD009061.

5.3.12.2 GCOS/CEOS Action A34; SS: A.11.1

Action: Ensure continuity of products based on space-based measurement of the precursors (NO2, SO2, HCHO and CO in particular) of ozone and aerosols and derive consistent emission databases, seeking to improve temporal and spatial resolution.
Who: Space agencies, in collaboration with national environmental agencies and meteorological services.
Time-Frame: Requirement has to be taken into account now in mission planning, to avoid a gap in the 2020 timeframe.
Performance Indicator: Availability of the necessary measurements, appropriate plans for future missions, and derived emission data bases.
Annual Cost Implications: 10-30M US$ (10% in non-Annex-I Parties).

2015 Update

The Canadian Space Agency approved the continuation of the SCISAT mission through the end of 2015. The atmospheric chemistry experiment (ACE) Fourier transform infrared spectrometer is unique in its ability to make measurements of upper atmosphere chemistry in the trace gases responsible for ozone depletion. A complete review of this experiment can be found at the following website http://www.ace.uwaterloo.ca/index.html

Limb Sounding Mission Gap

Participants in the CEOS Atmospheric Chemistry Virtual Constellation meeting of 2014 recognize the significance of the looming gap in limb sounding data. Following the demise of the currently operating but aging instruments:

- MLS on Aura (microwave emission),
- SMR (microwave emission) on Odin,
- OSIRIS (limb scatter UV-Vis-NIR) on Odin,
- ACE-FTS (solar occultation IR) on SCISAT, and
- ACE-MAESTRO (solar occultation UV-Vis-NIR) on SCISAT,

the only limb sounding instruments will be:

- OMPS Limb Profiler on Suomi-NPP (limb scatter UV-Vis-NIR),
- SAGE-III/ISS (solar occultation & limb scatter UV-Vis-NIR, planned for 2016),
- OMPS Limb Profiler on JPSS-2 (limb scatter UV-Vis-NIR, planned for ~2021).

Specific Deliverable #2
Maximize use of existing sensors and develop a collaborative framework to advocate and facilitate near-term calibration/validation activities and other coordinated science team planning for near-term space-based missions with limb sounding capability (e.g., to include, but not limited to, Stratospheric Aerosol and Gas Experiment (SAGE) III-ISS and Sentinel 5-Precursor) to maximize scientific output.

Aerosol_cci is developing and delivering a suite of aerosol property data sets from the following European instruments:

- ATSR-2 and AATSR (1995-2012)
- AATSR-SCIAMACHY synergy (2002-2012)
- AATSR-MERIS synergy (2002-2012)
- SEVIRI (2004-2015)
- IASI (2006-2015; Saharan dust region only)
- POLDER-1, POLDER-2 and PARASOL (1997, 2003, and 2005-2014; prototype products over Africa)
- OMI (2004-2015)
- GOMOS (2002-2012)

Notably the (A)ATSR product accuracies have been considerably improved, and quantitative product uncertainties developed. Product accuracies are comparable with the best NASA products, and show lower bias in their long term trends (see figure below). Products are assessed as part of the international GEWEX Aerosol Assessment. Aerosol_cci has also initiated the International Satellite Aerosol Science Network (AeroSAT) which is closely linked with AeroCom, AerChemMIP, ICAP, IGAC/SPARC CCMI, and ACPC.

References:

De Leeuw, G., and Coauthors, 2013: Evaluation of seven European aerosol optical depth retrieval algorithms for climate analysis. *Remote Sens. Environ.*, 162, 295–315, doi:10.1016/j.rse.2013.04.023.

Hollmann, R., and Coauthors, 2013: The ESA Climate Change Initiative: Satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, 94, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Holzer-Popp, T., and Coauthors, 2013: Aerosol retrieval experiments in the ESA Aerosol_cci project. *Atmos. Meas. Tech.*, **6**, 1919–1957, doi:10.5194/amt-6-1919-2013.

Kolmonen, P., A.-M. Sundström, L. Sogacheva, E. Rodriguez, T. Virtanen, and G. de Leeuw, 2013: Uncertainty characterization of AOD for the AATSR dual and single view retrieval algorithms. *Atmos. Meas. Tech. Disc.*, **6**, 4039–4075, doi:10.5194/amtd-6-4039-2013.

Zieger, P., and Coauthors, 2012: Spatial variation of aerosol optical properties around the high-alpine site Jungfraujoch (3580 m a.s.l.). *Atmos. Chem. Phys.*, **12**, 7231–7249, doi:10.5194/acp-12-7231-2012.

Zieger, P., and Coauthors, 2011: Comparison of ambient aerosol extinction coefficients obtained from in-situ, MAX-DOAS and LIDAR measurements at Cabauw. *Atmos. Chem. Phys.*, **11**, 2603–2624, doi:10.5194/acp-11-2603-2011.

5.4.2.1 GCOS/CEOS Action O4; SS O.1

Action: Ensure coordination of contributions to CEOS Virtual Constellations for each ocean surface ECV, in relation to *in situ* ocean observing systems.
Who: Space agencies, in consultation with CEOS Virtual Constellation teams, JCOMM, and GCOS.
Time-Frame: Continuous.
Performance Indicators: Annually updated charts on adequacy of commitments to space-based ocean observing system from CEOS.
Annual Cost Implications: <1M US$ (Mainly by Annex-I Parties and implementation cost covered in Actions below).

2015 Update

CEOS has added a Sea Surface Virtual Constellation in late 2011. Other continuing CEOS ocean Virtual Constellations include Ocean Color Radiometry, Ocean Surface Topography, and Ocean Surface Vector Wind. Additional CEOS ocean virtual constellations will be considered if and when a need arises.

5.4.3.1 GCOS/CEOS Action O7; SS: O.1

Action: Continue the provision of best possible SST fields based on a continuous coverage-mix of polar orbiting IR and geostationary IR measurements, combined with passive microwave coverage, and appropriate linkage with the comprehensive *in situ* networks noted in O8.
Who: Space agencies, coordinated through CEOS, CGMS, and WMO Space Programme.
Time-Frame: Continuing.
Performance Indicator: Agreement of plans for maintaining a CEOS Virtual Constellation for SST.
Annual Cost Implications: 1-10M US$ (for generation of datasets) (Mainly by Annex-I Parties).

2015 Update

Deliverable #1

- The ESA Climate Change Initiative (CCI) Sea Surface Temperature project (SST_cci, see http://www.esa-sst-cci.org/) is creating new Climate Data Records (CDRs) of SST from satellite retrievals. The project began in August 2010 and has been extended until 2016. The project scope includes user requirements gathering, algorithm development, algorithm benchmarking, data production and validation, disseminating those data, and obtaining user feedback. ESA SST CCI products are designed as stable, low-bias SST data starting during 1991 and continuing to 31 December 2010 (referred to as the 'long term' product). Each SST has associated with it a total uncertainty estimate, and uncertainty estimates for various contributions to that total uncertainty. Future versions of the datasets now in development will span at least 1982–2016, better addressing the need in many climate applications for stable records of global SST that are at least 30 years in length. A user guide is available at http://www.esa-sst-cci.org/PUG/guide.htm. The datasets generated to date by SST CCI are available at http://www.esa-sst-cci.org and from the Centre for Environmental Data Archival via the page http://www.neodc.rl.ac.uk.
- NASA maintains a 1km resolution global coverage SST analysis called the Multiscale Ultrahigh Resolution (MUR) L4 analysis based on nighttime satellite SST observations from several satellite instruments. Data are available at https://podaac.jpl.nasa.gov/dataset/JPL-L4UHfnd-GLOB-MUR.
- NOAA also produces and provides the AVHRR Pathfinder SST Climate Data Record. Currently, Verison 5.2 is available, spanning 1981-2012 in Level 3 Collated form (Casey et al., 2011: http://dx.doi.org/10.7289/V5WD3XHB). In 2015 NOAA will release Version 5.3, which will span 1981-2013 and include Level 2,

Level 3 Uncollated, and Level 3 Collated products. (http://www.nodc.noaa.gov/SatelliteData/pathfinder4km/)

- NOAA 1/4° daily Optimum Interpolation Sea Surface Temperature (or daily OISST, http://www.ncdc.noaa.gov/oisst) is an analysis constructed by combining observations from different platforms (satellites, ships, buoys) on a regular global grid. A spatially complete SST map is produced by interpolating to fill in gaps. Two analyses are produced: AVHRR-Only refers to the OISST that uses satellite SSTs only from from AVHRR and the AVHRR+AMSR uses AVHRR and additional data from AMSR-E, available from 2002 to 2011. The system also produces an anomaly field, an estimate of uncertainty and an estimate of sea ice concentration. A range of different data access points are available at http://www.ncdc.noaa.gov/oisst/data-access.
- A blended IR+MW satellite climate SST product has been developed by NASA/Remote Sensing Systems from Jume 2002 to present. A separate product covering the region 40N to 40S is available from January 1998. Data are available at http://www.remss.com/measurements/sea-surface-temperature.
- JAXA plan to produce a global coverage MW SST climate data product based on AMSRE and AMSR2.
- The EUMETSAT OSI-SAF plans to initiate MSG SEVIRI reprocessing of SST in 2015 in support of climate SST.
- The CEOS SST-VC is developing a white paper to describe a justified vision for the SST satellite constellation to address the needs of the SST application community including climate research.
- The Copernicus Sentinel-3 Sea and Land Surface Temperature Radiometer (SLSTR) will make all L1b data sets available to the international community in a free and open manner.
- JMA released Himawari-8 L1 data to research community in March 2015, and data is (will be) released from four coordinating universities/agencies outside JMA, including JAXA.
- JAXA plan to distribute Himawari-8 L1 in July 2015, and release Himawari-8 SST in July or August 2015.
- JAXA released GPM/GMI SST to public in March 2015 through JAXA GHRSST server. JAXA also released GCOM-W/AMSR2 10-GHz SST to public in April 2015 as research product.
- ESA has run a series of studies to investigate the development of a new C-band passive microwave SST radiometer mission (called Microwat) having a real aperture of ~15 km. Both conical-scanning and intefreometer concepts have been studied. An optimal mission would be one flying in convoy with MetOp which would provide scatterometer and higher frequency passive moicrowave measuirments to complement the Micopwat C-band measurments.

- The following satellite launches are planned in the coming few years:

Mission	**Lead Agency**	**Expected Launch date**
Sentinel-3A SLSTR	ESA/EC/EUMETSAT	2015
Sentinel-3B SLSTR	ESA/EC/EUMETSAT	2017
JPSS-1 VIIRS	NOAA/NASA	2017
JPSS-2 VIIRS	NOAA/NASA	2021
GOES-R	NOAA	2016
GCOM-C SGLI	JAXA	2016
MSG-4 SEVIRI	EUMETSAT	2015
MetOp-C AVHRR/3	EUMETSAT	2018
Himawari-9 AHI	JMA	2016

Deliverable #2:

- The ESA SST_cci project has completed an exahstive user requirements survey for climate SST users thich is available at http://www.esa-sst-cci.org/PUG/documents.
- The GHRSST International Project Office is developing a User Requirements Survey for SST products including climate data users.
- ESA has initiated a project called Fiducial Measurements for Satellite SST (FRM4CEOS) to inter-calibrate ship-borne infrared radiometers used for satellite validation. This follows on from previous CEOS activities conducted at the University of Miami and will ensure SI traceability of rasdiometers. In addition, a study to consider how best to address the ttraceability of in situ data sources has also been initiated.
- The ESA SST_cci project held a dedicated workshop on the user requirements for uncertainty information for SST Climate Data Records at the Met Office, UK. A report is available at http://www.esa-sst-cci.org/PUG/workshop.htm, a signficiant conclusion being that many major users favour ensemble CDRs for SST.

Deliverable #3

- Coordination of SST activities at the international level is through the GHRSST/CEOS SST-VC meachanism. As part of this effort, the GHRSST Climate Data Record Technical Advisory Group (CDR-TAG) focuses on the creation of delayed mode Climate Data Record products with higher accuracy and consistency, linking GHRSST products to longer term climate records and historical SST reconstructions and enabling a sustained reprocessing capability for both individual satellite sensor data and multi-sensor blended reanalysis products. A specific Climate Data assessment Framework (CDAF, available at https://www.ghrsst.org/files/download.php?m=documents&f=140204110029-CDRTAGCDAFv104.pdf) has been developed to understand the suitability of GHRSST datasets for use as Climate Data Records (CDRs). The CDAF sets out how the CDR-TAG will discharge this responsibility by providing authoritative, comparable information about GHRSST datasets that will allow users to make their own judgment about use of the datasets as CDRs for their application.The SST_cci project has conducted a Climate Assessment Report based on a validation and assessment of SST_cci data products by the project and international user community available at http://www.esa-sst-cci.org/PUG/documents

- An inter-comparison of ten global SST analyses is provided by the Met Office, United Kingdom as a contribution to GHRSST/CEOS SST-VC activities at http://ghrsst-pp.metoffice.com/pages/latest_analysis/sst_monitor/daily/ens/. This system provides a means to investigate differences between various analysis methodologies, technical and practical choices made by different analysis designs. In future, a version of this system dedicated to SST climate reanalyses would be useful.

Deliverable #4

- GHRSST continues to coordinate various Technical Advisory Groups and Working grous (validation, inter-comparison, diurnal variability, high-latitude SST, Estimation and retreivals) that coordinate activities of SST research and development.
- A number of high-resolution drifting buoys reporting SST have been developed and deployed by the Data Buoy Cooperation Panel (DBCP) to assess their impact on satellite SST validation.
- A number of high-resolution Argo profiling floats have been developed and deployed (Anderson and Riser, 2014) allowing further research of diurnal variability.
- The ESA SST_cci has initiated research to investigate the use of Argo as a validation tool for SST climate data products.
- The GODAE Ocean View Science Team Observing system Evaluation Task Team (OSEval-TT) has performed several OSE including SST https://www.godae-oceanview.org/science/task-teams/observing-system-evaluation-tt-oseval-tt.

References:

Anderson, J. and S. Riser (2014) Near-surface variability of temperature and salinity in the tropical and subtropical ocean: observations from profiling floats. Journal of Geophysical Research-Oceans, 119, doi:10.1002/2014JC010112

Casey, K. S., and Coauthors, 2011: AVHRR Pathfinder version 5.2 level 3 collated (L3C) global 4km sea surface temperature. National Oceanographic Data Center, NOAA. Dataset. doi:10.7289/V5WD3XHB [21 May 2015]

Bulgin, C. E., S. Eastwood, O. Embury, C. J. Merchant, and C. Donlon, 2014: The sea surface temperature climate change initiative: Alternative image classification algorithms for sea-ice affected oceans. *Remote Sens. Environ.*, 162, 396–407, doi:10.1016/j.rse.2013.11.022.

Hollmann, R., and Coauthors, 2013: The ESA Climate Change Initiative: satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, **94**, 1541–1552, doi:10.1175/BAMS-D-11-00254.1

Merchant, C. J., and Coauthors, 2012: A 20 year independent record of sea surface temperature for climate from Along-Track Scanning Radiometers. *J. Geophys. Res. Oceans*, **117**, C12013, doi:10.1029/2012JC008400.

Merchant, C. J., and Coauthors, 2014: Sea surface temperature datasets for climate applications from Phase 1 of the European Space Agency Climate Change Initiative (SST CCI). *Geosci. Data J.*, **1**, 179–191, doi:10.1002/gdj3.20.

Zhang, H.-M., R. W. Reynolds, and T. M. Smith, 2006: Adequacy of the in situ observing system in the satellite era for climate SST. *J. Atmos. Oceanic Technol.*, **23**, 107–120, doi:10.1175/JTECH1828.1.

5.4.4.1 GCOS/CEOS Action O10; SS: O.3

Action: Ensure continuous coverage from one higher-precision, medium-inclination altimeter (the "Reference Mission" and two medium-precision, higher-inclination altimeters ("Complementary Missions").

Who: Space agencies, with coordination through the CEOS Constellation for Ocean Surface Topography, CGMS, and the WMO Space Programme.

Time-Frame: Continuous.

Performance Indicator: Satellites operating, and provision of data to analysis centres.

Annual Cost Implications: 30-100M US$ (Mainly by Annex-I Parties).

2015 Update

The major achievements realised by the Sea_Level CCI project consist of:

(1) improved and homogeneous reprocessing of altimetry data from ERS-1, ERS-2, Envisat, TOPEX/Poseidon, Jason-1, Jason-2, GeoSat and GFO (plus additional data from CryoSat, Altika, Sentinel-3 and Jason-3, the two former in preparation, the two latter depending on launch date) based on new orbit solutions, improved wet tropospheric corrections and tidal corrections, etc., with the goal to provide an accurate 23-year long (1993-2015) sea level record (FCDR and the ECVs global mean and gridded sea level time series),

(2) production of formal errors for all the products, with a comprehensive error characteristic analysis.

(3) investigation of specific technical issues, such as Arctic sea-level during sea-ice minima, coastal sea-level change, etc.

By combining the Sea Level_CCI products with other CCI ECVs (glaciers, ice sheets, sea surface temperature, etc.), improved sea level budget studies have been performed at global and regional

scales, allowing estimates of unknown -or poorly known- contributions (e.g., the deep ocean heat uptake and its role in the current 'hiatus' or the land water storage change due to human activities). Products were developed in the framework of the Ocean Surface Topography Science Team (OSTST) and the Global Sea Level Observing System (GLOSS).
See: http://www.esa-sealevel-cci.org

See also CEOS ocean surface topography virtual constellation link at http://ceos.org/ourwork/virtual-constellations/ost/.

References:

Ablain, M., and Coauthors, 2014: Improved sea level record over the satellite altimetry era (1993–2010) from the Climate Change Initiative Project. *Ocean Sci. Disc.*, **11**, 2029–2071, doi:10.5194/osd-11-2029-2014.

Ablain, M., A. Cazenave, G. Valladeau, and S. Guinehut, 2009: A new assessment of the error budget of global mean sea level rate estimated by satellite altimetry over 1993–2008. *Ocean Science*, **5**, 193–201, doi:10.5194/os-5-193-2009.

Ablain, M., S. Philipps, M. Urvoy, N. Tran, and N. Picot, 2012: Detection of long-term instabilities on altimeter backscatter coefficient thanks to wind speed data comparisons from altimeters and models. *Marine Geod.*, **35**(sup1), 258–275. doi:10.1080/01490419.2012.718675

Cazenave, A., H.-B. Dieng, B. Meyssignac, K. von Schuckmann, B. Decharme, and E. Berthier, 2014: The rate of sea-level rise. *Nature Climate Change*, **4**, 358–361, doi:10.1038/nclimate2159.

Cazenave, A., and Coauthors, 2012:. Estimating ENSO influence on the global mean sea level, 1993–2010. *Marine Geod.*, **35**(sup1), 82–97, doi:10.1080/01490419.2012.718209.

Couhert, A., and Coauthors, 2015: Towards the 1mm/y stability of the radial orbit error at regional scales. *Adv. Space Res.*, **55**, 2–23, doi:10.1016/j.asr.2014.06.041.

Dieng, H. B., H. Palanisamy, A. Cazenave, B. Meyssignac, and K. von Schuckmann, 2015: The sea level budget since 2003: Inference on the deep ocean heat content. *Surv. Geophys.*, **36**, 209–229, doi:10.1007/s10712-015-9314-6.

Feng, X., M. N. Tsimplis, G. D. Quartly, and M. J. Yelland, 2014: Wave height analysis from 10 years of observations in the Norwegian Sea. *Continental Shelf Res.*, **72**, 47–56, doi:10.1016/j.csr.2013.10.013.

Feng, X., M. N. Tsimplis, M. J. Yelland, and G. D. Quartly, 2014: Changes in significant and maximum wave heights in the Norwegian Sea. *Global Planet. Change*, **113**, 68–76, doi:10.1016/j.gloplacha.2013.12.010.

Henry, O., M. Ablain, B. Meyssignac, A. Cazenave, D. Masters, S. Nerem, and G. Garric, 2013: Effect of the processing methodology on satellite altimetry-based global mean sea level rise over the Jason-1 operating period. *J. Geodesy*, **88**, 351–361, doi:10.1007/s00190-013-0687-3.

Hollmann, R., and Coauthors, 2013. The ESA Climate Change Initiative: Satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, **94**, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Johannessen, J. A., and Coauthors, 2014: Toward improved estimation of the dynamic topography and ocean circulation in the high latitude and Arctic Ocean: The Importance of GOCE. *Surv. Geophys.*, **35**, 661–679, doi:10.1007/s10712-013-9270-y.

Legeais, J.-F., M. Ablain, and S. Thao, 2014: Evaluation of wet troposphere path delays from atmospheric reanalyses and radiometers and their impact on the altimeter sea level. *Ocean Science*, **10**, 893–905, doi:10.5194/os-10-893-2014.

Masters, D., R. S. Nerem, C. Choe, E. Leuliette, B. Beckley, N. White, and M. Ablain, 2012: Comparison of global mean sea level time series from TOPEX/Poseidon, Jason-1, and Jason-2. *Marine Geod.*, **35**(sup1), 20–41, doi:10.1080/01490419.2012.717862.

Ollivier, A., Y. Faugere, N. Picot, M. Ablain, P. Femenias, and J. Benveniste, 2012: Envisat ocean altimeter becoming relevant for mean sea level trend studies. *Marine Geod.*, **35**(sup1), 118–136, doi:10.1080/01490419.2012.721632.

Palanisamy, H., A. Cazenave, T. Delcroix, and B. Meyssignac, 2015: Spatial trend patterns in the Pacific Ocean sea level during the altimetry era: the contribution of thermocline depth change and internal climate variability. *Ocean Dynamics*, **65**, 341–356, doi:10.1007/s10236-014-0805-7.

Palanisamy, H., A. Cazenave, B. Meyssignac, L. Soudarin, G. Wöppelmann, and M. Becker, 2014: Regional sea level variability, total relative sea level rise and its impacts on islands and coastal zones of Indian Ocean over the last sixty years. *Global Planet. Change*, **116**, 54–67, doi:10.1016/j.gloplacha.2014.02.001.

Passaro, M., P. Cipollini, S. Vignudelli, G. D. Quartly, and H. M. Snaith, 2014: ALES: A multi-mission adaptive subwaveform retracker for coastal and open ocean altimetry. *Remote Sens. Environ.*, **145**, 173–189. doi:10.1016/j.rse.2014.02.008.

Prandi, P., M. Ablain, A. Cazenave, and N. Picot, 2012: A new estimation of mean sea level in the Arctic Ocean from satellite altimetry. *Marine Geod.*, **35**(sup1), 61–81, doi:10.1080/01490419.2012.718222.

Rudenko, S., and Coauthors, 2014: Influence of time variable geopotential models on precise orbits of altimetry satellites, global and regional mean sea level trends. *Adv. Space Res.*, **54**, 92–118, doi:10.1016/j.asr.2014.03.010.

Valladeau, G., J. F. Legeais, M. Ablain, S. Guinehut, and N. Picot, 2012: Comparing altimetry with tide gauges and Argo profiling floats for data quality assessment and mean sea level studies. *Marine Geod.*, **35**(sup1), 42–60, doi:10.1080/01490419.2012.718226.

5.4.5.1 GCOS/CEOS Action O12; SS: O.2

Action: Research programmes should investigate the feasibility of utilizing satellite data to help resolve global fields of sea surface salinity.
Who: Space agencies, in collaboration with the ocean research community.
Time-Frame: Feasibility studies complete by 2014.
Performance Indicator: Reports in literature and to OOPC.
Annual Cost Implications: 1-10M US$ (Mainly by Annex-I Parties).

2015 Update

Sea surface salinity missions now in orbit include the ESA Soil Moisture and Ocean Salinity (SMOS) launched in 2009 and the NASA Aquarius launched in 2011. ESA and NASA have funded research programs using these data and producing global fields of sea surface salinity merging all available observations. The results of these programs were summarized in an ocean salinity meeting in November 2014 (http://www.oceansalinityscience2014.org/)

5.4.6.1 GCOS/CEOS Action O15; SS: O.6.1

Action: Implement continuity of ocean colour radiance datasets through the plan for an Ocean Colour Radiometry Virtual Constellation.
Who: CEOS space agencies, in consultation with IOCCG and GEO.
Time-Frame: Continuing.
Performance Indicator: Global coverage with consistent sensors operating according to the GCMPs; flow of data into agreed archives.
Annual Cost Implications: 30-100M US$ (10% in non-Annex-I Parties).

2015 Update

The CEOS OCR-VC continues to actively coordinate Space Agency plans for instrumentation from both polar and geostationary satellites. The OCR-VC works in collaboration with the International Ocean Colour Coordinating Group (IOCCG) and has recently updated plans for ocean color sensors from geostationary orbit (IOCCG Report 12), sensor requirements (IOCCG Report 13), and in flight calibration (IOCCG Report 14) all available from the IOCCG.org web site.

With respect to ECV generation, International efforts to produce time series of ECVs include:

- NASA-GSFC: Lw and Chl time series from SeaWiFS, Aqua, Terra, MERIS
- MEaSUREs (NASA): inherent optical properties (IOPs) from SeaWiFS, Aqua, MERIS
- GLOBColour (ESA): time series of merged data from SeaWiFS, Aqua, MERIS
- ESA's CCI program: new (Dec 2013) merged and bias corrected times series from MERIS, MODIS, SeaWiFS with associated per-pixel uncertainty information. The following ECV products are being delivered from a multi-mission combination of SeaWiFS, MODIS/Aqua, MERIS, and eventually VIIRS and Sentinel-3 OLCI

observations. The following products are being delivered, covering the time period 1997-2015:

- o Water-leaving radiances (412, 443, 490, 510, 555 and 670 nm)
- o Chlorophyll-a concentration, diffuse attenuation coefficient (490 nm) and inherent optical properties (412, 443, 490, 510, 555 and 670 nm).

Additional tests are performed on earlier CZCS data from 1978-1986. The products cover Case 1 waters (oceanic) and plans are underway to develop prototype ECV products for Case 2 (coastal) waters.

Work is being conducted in consultation with the International Ocean Colour Coordinating Group and the OCR Virtual Constellation. Close collaboration with the NASA Ocean Biology Processing Group and NASA MEaSURES project has been maintained throughout.

See: www.esa-oceancolour-cci.org

Next steps for progress in climate uses of ocean color include:

- Evaluate differences among existing OCR ECV products
- Recommend comparison/evaluation metrics
- Identify opportunities for further improvement
- Encourage convergence on a cooperative approach for a common product assessment or common processing approach

References:

Brewin, R. J. W., G. Dall'Olmo, S. Sathyendranath, and N. J. Hardman-Mountford, 2012: Particle backscattering as a function of chlorophyll and phytoplankton size structure in the open-ocean. *Optics Express*, **20**, 17632–17652, doi:10.1364/OE.20.017632.

Brewin, R. J. W., E. Devred, S. Sathyendranath, S. J. Lavender, and N. J. Hardman-Mountford, 2011: Model of phytoplankton absorption based on three size classes. *Applied Optics*, **50**, 4535–4549, doi:10.1364/AO.50.004535.

Brewin, R. J. W., D. E. Raitsos, Y. Pradhan, and I. Hoteit, 2013: Comparison of chlorophyll in the Red Sea derived from MODIS-Aqua and in vivo fluorescence. *Remote Sens. Environ.*, **136**, 218–224, doi:10.1016/j.rse.2013.04.018.

Brewin, R. J. W., and Coauthors, 2015: The Ocean Colour Climate Change Initiative: III. A round-robin comparison on in-water bio-optical algorithms. *Remote Sens. Environ.*, **162**, 271–294, doi:10.1016/j.rse.2013.09.016.

Brotas, V., and Coauthors, 2013: Deriving phytoplankton size classes from satellite data: Validation along a trophic gradient in the eastern Atlantic Ocean. *Remote Sens. Environ.*, **134**, 66–77, doi:10.1016/j.rse.2013.02.013.

Ciavatta, S., R. Torres, V. Martinez-Vicente, T. Smyth, G. Dall'Olmo, L. Polimene, and J. I.Allen, 2014: Assimilation of remotely-sensed optical properties to improve marine biogeochemistry modelling. *Progr. Oceanogr.*, **127**, 74–95, doi:10.1016/j.pocean.2014.06.002.

Ciavatta, S., R. Torres, S. Saux-Picart, and J. I. Allen, 2011: Can ocean color assimilation improve biogeochemical hindcasts in shelf seas? *J. Geophys. Res. Oceans*, **116**, C12043, doi:10.1029/2011JC007219.

Devred, E., S. Sathyendranath, V. Stuart, and T. Platt, 2011: A three component classification of phytoplankton absorption spectra: Application to ocean-color data. *Remote Sens. Environ.*, **115**, 2255–2266, doi:10.1016/j.rse.2011.04.025.

Garcia-Soto, C., and Coauthors, 2012: The influence of the Indian Ocean Dipole on interannual variations in phytoplankton size structure as revealed by Earth Observation. *Deep Sea Res. Part II*, **77**, 117–127, doi:10.1016/j.dsr2.2012.04.009.

Hollmann, R., and Coauthors, 2013: The ESA Climate Change Initiative: Satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, **94**, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Mélin, F., and G. Sclep, 2015: Band shifting for ocean color multi-spectral reflectance data. *Optics Express*, **23**, 2262–2279, doi:10.1364/OE.23.002262.

Mélin, F., and V. Vantrepotte, 2015: How optically diverse is the coastal ocean? *Remote Sens. Environ.*, **160**, 235–251, doi:10.1016/j.rse.2015.01.023.

Mélin, F., and Coauthors, 2011: Assessment of MERIS reflectance data as processed with SeaDAS over the European seas. *Optics Express*, **19**, 25657–25671, doi:10.1364/OE.19.025657.

Melin, F., G. Zibordi, B. N. Holben, 2013: Assessment of the aerosol products from the SeaWiFS and MODIS ocean-color missions. *IEEE Geosci. Remote Sens. Lett.*, **10**, 1185–1189, doi:10.1109/LGRS.2012.2235408.

Racault, M.-F., C. Le Quéré, E. Buitenhuis, S. Sathyendranath, and T. Platt, 2012: Phytoplankton phenology in the global ocean. *Ecolog. Indicators*, **14**, 152–163, doi:10.1016/j.ecolind.2011.07.010.

Raitsos, D. E., Y. Pradhan, R. J. W. Brewin, G. Stenchikov, and I. Hoteit, 2013: Remote sensing the phytoplankton seasonal succession of the Red Sea. *PloS One*, **8(6)**, e64909, doi:10.1371/journal.pone.0064909.

Roy, S., D. S. Broomhead, T. Platt, S. Sathyendranath, and S. Ciavatta, 2012: Sequential variations of phytoplankton growth and mortality in an NPZ model: A remote-sensing-based assessment. *J. Marine Syst.*, **92**, 16–29, doi:10.1016/j.jmarsys.2011.10.001.

Sathyendranath, S., and Coauthors, 2012: Ocean Colour Climate Change Initiative — Approach and initial results. In *2012 IEEE International Geoscience and Remote Sensing Symposium*, IEEE, pp. 2024–2027, doi:10.1109/IGARSS.2012.6350979.

Saux Picart, S., S. Sathyendranath, M. Dowell, T. Moore, and T. Platt, 2014: Remote sensing of assimilation number for marine phytoplankton. *Remote Sens. Environ.*, **146**, 87–96, doi:10.1016/j.rse.2013.10.032.

Steinmetz, F., P.-Y. Deschamps, and D. Ramon, 2011: Atmospheric correction in presence of sun glint: application to MERIS. *Optics Express*, **19**, 9783–800, doi:10.1364/OE.19.009783.

Zhai, L., and Coauthors, 2012: Phytoplankton phenology and production around Iceland and Faroes. *Continental Shelf Res.*, **37**, 15–25, doi:10.1016/j.csr.2012.01.013.

Zhai, L., C. Tang, T. Platt, and S. Sathyendranath, 2011: Ocean response to attenuation of visible light by phytoplankton in the Gulf of St. Lawrence. *J. Marine Syst.*, **88**, 285–297, doi:10.1016/j.jmarsys.2011.05.005.

Zibordi, G., B. Holben, F. Mélin, D. D'Alimonte, J.-F. Berthon, I. Slutsker, and D. Giles, 2010: AERONET-OC: An overview. *Canadian J. Remote Sens.*, **36**, 488–497, doi:10.5589/m10-073.

5.4.7.1 GCOS/CEOS Action O19; SS: O.5

Action: Ensure sustained satellite-based (microwave, SAR, visible and IR) sea-ice products.
Who: Parties' national services, research programmes and space agencies, coordinated through the WMO Space Programme and Global Cryosphere Watch, CGMS, and CEOS; National services for *in situ* systems, coordinated through WCRP CliC and JCOMM.
Time-Frame: Continuing.
Performance Indicator: Sea-ice data in International Data Centres.
Annual Cost Implications: 1-10M US$ (Mainly by Annex-I Parties).

2015 Update

The Sea Ice CCI project has developed and processed the following consistent multi-mission merged sea-ice ECV products:

- Sea ice concentration based on SSM/I (F10, F11, F13, F14, F15) (1992-2008) and AMSR-E (2002-2011);
- Winter Arctic sea ice thickness and freeboard from Envisat RA-2 (2002-2012) and Antarctic freeboard for Envisat RA-2 (2002-2012)

This is being complemented by:

- Sea ice concentration based on AMSR-E (2002-2011) and AMSR2 (2013-2015);
- Arctic sea ice thickness and freeboard and Antarctic freeboard from ERS-1 RA (1993-2000), ERS-2 RA (1995-2003), Envisat RA-2 (2002-2012), Cryosat-2 SIRAL2 (2010 ->) and Arctic thin ice sea ice thickness from SMOS (2009 ->)
- Sea ice drift: algorithm inter-comparison and product specifications for a new sea ice ECV.

The data are available at the Integrated Climate Data Center (ICDC) in Hamburg:
http://icdc.zmaw.de/esa-cci_sea-ice-ecv0.html?&L=1
Note: The Sea Ice Concentration products are developed in collaboration with EUMETSAT OSISAF.
See: http://esa-cci.nersc.co

Progress on Action O19: Ensure sustained satellite-based (microwave, SAR, visible and IR) sea-ice products

Primary sea ice products derived from satellites are concentration, extent/edge, thickness, and motion. Concentration, extent, and motion have primarily been derived from passive microwave instruments. These have a long-term legacy (since late 1978 for multichannel radiometers) and thus can provide information on climate trends and multidecadal variability. In addition, the instruments can collect data during night conditions and through most clouds, providing complete daily coverage. However, they do have substantial limitations.

First, passive microwave energy from the surface is modified by the atmosphere, particularly water vapor and liquid water. This affects the accuracy of uncertainty retrievals. Some work has been done to develop atmospheric corrections (e.g., Markus and Cavalieri, 2000), but the effectiveness of these has not yet been well validated. Another significant limitation is that during summer surface melt water and melt ponds on the ice are seen as reduced concentration. Finally, thin ice (less than ~30 cm) tends to be underestimated due to emission from below the ice surface; this limits accuracy near the ice edge during the growth season and in leads and polynyas (e.g., Meier, 2005).

Fortunately, the Arctic atmosphere is relatively dry and during winter when there is no melt, several validation studies (e.g., Comiso et al., 2003; Cavalieri et al., 2006; Andersen et al., 2007) have shown that concentration accuracy is within 5%. However, in less optimal regions (as discussed above) concentration biases may be 20% or more (Steffen et al., 1992; Meier, 2005).

Another limitation is low spatial resolution with gridded products at 25 km for much of the record, though more recent sensors and algorithms can provide 12 or 6 km resolution. This limits the precision at which the ice edge location can be estimated. While the low resolution is not a major limitation for large-scale climate studies, it severely limits the utility of passive microwave data for operational ice analyses.

SAR data is most useful for observing small-scale sea ice processes, such as lead and polynya formation, ridging, and estimating floe size (e.g., Kwok, 2002). The primary limitation of SAR is cost/accessibility and coverage. Another limitation is the complexity of the backscatter signal and the general need for manual interpretation. SAR is extremely valuable input into operational ice analyses.

Clouds significantly limit visible and infrared imagery. Visible data is only feasible during summer and infrared is most useful during winter because summer melt yields a nearly isothermal surface. Still, such data provide higher resolution than passive microwave, easier interpretation than SAR, and provide information on important flux parameters (e.g., albedo, temperature).

Sea ice thickness estimates from satellite has been limited because of the lack of altimeter coverage. Starting with the NASA ICESat mission in 2003, near-complete polar coverage was finally attained. However, due to limitations of the lasers, ICESat operations were limited to only two month-long campaigns per year. And ICESat failed before the launch of the radar altimeter on the ESA CryoSat-2 satellite. Airborne measurements from the NASA IceBridge project fill in some gaps and provide an intercalibration bridge between the instruments. Beyond the limited coverage of sea ice by sensors, there are considerable difficulty in obtaining thickness observations from the raw data due to the precision needed for the freeboard measurement to obtain a reasonable total thickness accuracy, and because of uncertainties in ice density, altimeter penetration depth (particularly for radar), and especially snow properties (especially depth and density). Nonetheless, thickness estimates have been produced from ICESat-2 (e.g., Kwok et al., 2009) and preliminary fields from CryoSat-2 (Laxon et al., 2013). Passive microwave data has from the new ESA SMOS sensor has shown the capability to obtain thickness of thin ice up to ~50 cm (Kaleschke et al., 2012) and visible/infrared imagery can also be used to calculate thickness up to a threshold level in concert with a radiative transfer model (Wang et al., 2010).

Sea ice motion is generally derived via cross-correlation feature matching algorithms (e.g., Emery et al., 1997). Thus any input imagery can be employed. Accuracy depends mostly on spatial resolution, with higher resolution providing greater accuracy. However, even though of lower resolution, passive microwave imagery has been the primary source of motion data because of its all-sky capabilities and complete daily coverage.

The future of satellite observations for sea ice is mixed. While passive microwave imagers have been the workhorses for sea ice products and the climate record produce from them is one of the most important from satellites, the long-term future is uncertain beyond 2020, perhaps sooner if sensors fail before planned lifetimes. At the moment, only ESA has preliminary plans for an operational passive microwave beyond 2020 and there could be a gap with current sensors. Overlaps between sensors are extremely important to be able to accurately intercalibrate and assure consistency over the time series and accurate trend estimates. SAR data has been primarily limited by cost because of the use of a commercial model. Future SAR missions with access to researchers and operational analysts are critical. There has already been a gap in thickness estimates from satellite altimeters and another gap is likely unless CryoSat-2 continues to operate beyond is nominal mission until the launch of ICESat-2 in 2017. Visible/infrared is likely more stable overall due to their importance of polar orbiting sensors for weather models. However, a gap is possible in U.S. capabilities if the current MODIS and VIIRS sensors fail before a replacement is launched.

References:

Andersen, S., R. Tonboe, L. Kaleschke, G. Heygster, and L.T. Pedersen, 2007: Intercomparison of passive microwave sea ice concentration retrievals over the high-concentration Arctic sea ice. *J. Geophys. Res.*, **112**, C08004, doi:10.1029/2006JC003543.

Cavalieri, D. J., T. Markus, D. K. Hall, A. J. Gasiewski, M. Klein, and A. Ivanoff, 2006: Assessment of EOS Aqua AMSR-E Arctic sea ice concentrations using Landsat-7 and airborne microwave imagery. *IEEE Trans. Geosci. Rem. Sens.*, **44**, 3057–3069, doi:10.1109/TGRS.2006.878445.

Comiso, J. C., D. J. Cavalieri, and T. Markus, 2003: Sea ice concentration, ice temperature, and snow depth using AMSR-E data. *IEEE Trans. Geosci. Rem. Sens.*, **41**, 243–252, doi:10.1109/TGRS.2002.808317.

Emery, W. J., C. W. Fowler, and J. A. Maslanik, 1997: Satellite-derived maps of Arctic and Antarctic sea ice motion: 1988 to 1994. *Geophys. Res. Lett.*, **24**, 897–900, doi:10.1029/97GL00755.

Heinrichs, J. F., D. J. Cavalieri, and T. Markus, 2006: Assessment of the AMSR-E Sea Ice-Concentration Product at the Ice Edge Using RADARSAT-1 and MODIS Imagery. *IEEE Trans. Geosci. Rem. Sens.*, **44**, 3070–3080, doi:10.1109/TGRS.2006.880622.

Hollmann, R., and Coauthors, 2013: The ESA Climate Change Initiative: Satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, 94, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Kaleschke, L., X. Tian-Kunze, N. Maaß, M. Mäkynen, and M. Drusch, 2012: Sea ice thickness retrieval from SMOS brightness temperatures during the Arctic freeze-up period. *Geophys. Res. Lett.*, **39**, L05501, doi:10.1029/2012GL050916, 2012.

Kern, S., and Coauthors, 2014:. About uncertainties in sea ice thickness retrieval from satellite radar altimetry: results from the ESA-CCI Sea Ice ECV Project Round Robin Exercise. *The Cryosphere Disc.*, **8**, 1517–1561, doi:10.5194/tcd-8-1517-2014

Kwok, R., 2002: Sea ice concentration from passive microwave radiometry and openings from SAR ice motion. *Geophys. Res. Lett*, **29**, 1311, doi:10.1029/2002GL014787.

Kwok, R., G. F. Cunningham, M. Wensnahan, I. Rigor, H. J. Zwally, and D. Yi, 2009: Thinning and volume loss of Arctic sea ice: 2003-2008. *J. Geophys. Res. Oceans*, **114**, C07005, doi:10.1029/2009JC005312.

Laxon, S. W., and Coauthors, 2013: CryoSat-2 estimates of Arctic sea ice thickness and volume. *Geophys. Res. Lett.*, **40**, 732–737, doi:10.1002/grl.50193.

Markus, T., and D. J. Cavalieri, 2000: An enhancement of the NASA Team sea ice algorithm. *IEEE Trans. Geosci. Rem. Sens.*, **38**, 1387-1398, doi:10.1109/36.843033.

Meier, W. N., 2005: Comparison of passive microwave ice concentration algorithm retrievals with AVHRR imagery in arctic peripheral seas. *IEEE Trans. Geosci. Rem. Sens.*, **43**, 1324–1337, doi:10.1109/TGRS.2005.846151.

Steffen, K., and Coauthors, 1992. The estimation of geophysical parameters using passive microwave algorithms. In *Microwave Remote Sensing of Sea Ice*, F. D. Carsey, Ed., *AGU Geophysical Monograph 68*, pp. 47–71.

Wang, X., J. R. Key, and Y. Liu, 2010: A thermodynamic model for estimating sea and lake ice thickness with optical satellite data. *J. Geophys. Res. Oceans*, **115**, C12035, doi:10.1029/2009JC005857.

5.4.8.1 GCOS/CEOS Action O28; SS: N/A

Action: Develop projects designed to assemble the *in situ* and satellite data into a composite reference reanalysis dataset, and to sustain projects to assimilate the data into models in ocean reanalysis projects.

Who: Parties' national ocean research programmes and space supported by WCRP.

Time-Frame: Continuous.

Performance Indicator: Project for data assembly launched, availability and scientific use of ocean reanalysis products.

Annual Cost Implications: 1-10M US$ (10% in non-Annex-I Parties).

2015 Update

The CEOS-CGMS Working Group on Climate has endorsed the observations for model intercomparison (Obs4MIPS) to facilitate the use and intercomparison of space-based ECVs with model and re-analysis data sets.

5.4.9.1 GCOS/CEOS Action O41; SS N/A

Action: Promote and facilitate research and development (new improved technologies in particular), in support of the global ocean observing system for climate.
Who: Parties' national ocean research programmes and space agencies, in cooperation with GOOS, GCOS, and WCRP.
Time-Frame: Continuing.
Performance Indicator: More cost-effective and efficient methods and networks; strong research efforts related to the observing system; number of additional ECVs feasible for sustained observation; improved utility of ocean climate products.
Annual Cost Implications: 30-100M US$ (10% in non-Annex-I Parties).

2015 Update

The CEOS-CGMS Working Group on Climate is supporting the GEO Blue Planet initiative that seeks to bring together all the existing ocean observation programmes within GEO, to add new ones to the GEO portfolio, and to create synergies between them.

5.5.2.1 GCOS/CEOS Action T5; SS: T.12

Action: Develop an experimental evaporation product from existing networks and satellite observations.
Who: Parties, national services, research groups through GTN-H, the Integrated Global Water Cycle Observations (IGWCO) partners, TOPC, GEWEX Land Flux Panel and WCRP CliC.
Time frame: 2013-2015.
Performance indicator: Availability of a validated global satellite product of total evaporation.
Annual Cost Implications: 1-10M US$ (10% in non-Annex-I Parties).

2015 Update

Space Agencies have funded efforts to produce evaporation products from in situ and satellite data through the use of surface energy balance models. These efforts are coordinated by the WCRP GEWEX Data and Assessment Panel.

5.5.3.1 GCOS/CEOS Action T8; SS: T.1.1 and T.1.2

Action: Submit weekly/monthly lake level/area data to the International Data Centre; submit weekly/monthly altimeter-derived lake levels by space agencies to HYDROLARE.
Who: National Hydrological Services through WMO CHy, and other institutions and agencies providing and holding data; space agencies; HYDROLARE.
Time-Frame: 90% coverage of available data from GTN-L by 2012.
Performance Indicator: Completeness of database.
Annual Cost Implications: 1-10M US$ (40% in non-Annex-I Parties).

2015 Update

Lake level was routinely reported by the ENVISAT altimeter until the end of the mission in May 2012. Lake levels are currently reported by the ISRO Satellite with ARgos and ALtiKa (SARAL) mission.

5.5.3.2 GCOS/CEOS Action T10; SS: N/A

Action: Submit weekly surface and sub-surface water temperature, date of freeze-up and date of break-up of lakes in GTN-L to HYDROLARE.
Who: National Hydrological Services and other institutions and agencies holding and providing data; space agencies.
Time-frame: Continuous.
Performance Indicator: Completeness of database
Annual Cost Implications: <1M US$ (40% in non-Annex-I Parties).

2015 Update

There is no update of this action available.

5.5.4.1 GCOS/CEOS Action T13; SS: T.11

Action: Develop a record of validated globally-gridded near-surface soil moisture from satellites.
Who: Parties' national services and research programmes, through GEWEX and TOPC in collaboration with space agencies.
Time frame: 2014.
Performance indicator Availability of globally validated soil moisture products from the early satellites until now.
Annual Cost Implications: 1-10M US$ (10% in non-Annex-I Parties).

2015 Update

- The successful completion of the ESA project WACMOS in 2012 provided the functional design of the CCI SM production system.
- Building upon the work undertaken in WACMOS, in collaboration with ESA's CCI SM project, June 2012 saw the release of the first 30+ year, global, soil moisture project derived from active and passive EO data sets.
- The third data set (product) release of CCI SM v02.1 was made in Sept 2014 providing 35 years of data from 1978 onwards, and is freely available, after registration, via http://www.esa-soilmoisture-cci.org/

- As provided in the recently authored Product Validation and Intercomparison Report (Nov 2014), available from CCI SM web site (Jan 2015), the CCI SM data set has been successfully, independently, validated and compared against in situ, modelled and other satellite datasets.
- A review of the CCI phase 1 SM product in January 2014, using the modified bates maturity index of the CORE-CLIMAX project, resulted in an overall score of 3 (Initial Operations Capacity).
- Since the first product release in 2012 more than 1200 users have registered to date to obtain the product. The product enjoys a global uptake with the majority of users coming from the USA, China and India, and a strong following across the EU, and Australasia. The users focus largely on Climate, Water and Ecosystem issues, although Disaster and Agriculture are also key topics
- Following the successful completion of CCI SM phase 1 in Dec 2014, phase 2 (CCI SM 2) started on 1.1. 2015, running to 31.12.2017 and, in close collaboration with user groups, sees the graceful evolution of the implementation of the production system towards an operational system.
- CEOS WGCV, through the Focus Area on Soil Moisture within the Land Product Validation Subgroup, has taken on a coordination role for the validation and inter-comparison of satellite-derived soil moisture products.

References:

Albergel, C., and Coauthors, 2013: Monitoring multi-decadal satellite earth observation of soil moisture products through land surface reanalyses. *Remote Sens. Environ.*, **138**, 77–89, doi:10.1016/j.rse.2013.07.009.

Albergel, C., and Coauthors, 2013: Skill and global trend analysis of soil moisture from reanalyses and microwave remote sensing. *J. Hydrometeor.*, **14**, 1259–1277, doi:10.1175/JHM-D-12-0161.1.

Atmospheric science: Detecting rainfall from the bottom up. *Nature*, **509**, 262–263. doi:10.1038/509262e.

Barichivich, J., and Coauthors, 2014: Temperature and snow-mediated moisture controls of summer photosynthetic activity in northern terrestrial ecosystems between 1982 and 2011. *Remote Sens.*, **6**, 1390–1431, doi:10.3390/rs6021390.

Barrett, B., I. Nitze, S. Green, and F. Cawkwell, 2014: Assessment of multi-temporal, multi-sensor radar and ancillary spatial data for grasslands monitoring in Ireland using machine learning approaches. *Remote Sens. Environ.*, **152**, 109–124, doi:10.1016/j.rse.2014.05.018.

Bauer-Marschallinger, B., W. A. Dorigo, W. Wagner, and A. I. J. M. van Dijk, 2013: How oceanic oscillation drives soil moisture variations over mainland Australia: An analysis of 32 years of satellite observations. *J. Climate*, **26**, 10159–10173, doi:10.1175/JCLI-D-13-00149.1.

Brocca, L., and Coauthors, 2014:. Soil as a natural rain gauge: Estimating global rainfall from satellite soil moisture data. *J. Geophys. Res. Atmos.*, **119**, 5128–5141, doi:10.1002/2014JD021489.

Chen, T., R. A. M. de Jeu, Y. Y. Liu, G. R. van der Werf, and A. J. Dolman, 2014: Using satellite based soil moisture to quantify the water driven variability in NDVI: A case study over mainland Australia. *Remote Sens. Environ.*, **140**, 330–338, doi:10.1016/j.rse.2013.08.022.

De Jeu, R. A. M., W. A. Dorigo, R. M. Parinussa, W. Wagner, and D. Chung, 2012: Soil moisture [in “State of the Climate in 2011”]. *Bull. Amer. Meteor. Soc.*, **93**(7), S30–S34.

De Jeu, R. A. M., T. R. H. Holmes, R. M. Parinussa, and M. Owe, 2014: A spatially coherent global soil moisture product with improved temporal resolution. *J. Hydrol.*, **516**, 284–296, doi:10.1016/j.jhydrol.2014.02.015.

Diodato, N., L. Brocca, G. Bellocchi, F. Fiorillo, and F. M. Guadagno, 2014: Complexity-reduction modelling for assessing the macro-scale patterns of historical soil moisture in the Euro-Mediterranean region. *Hydrolog. Processes*, **28**, 3752–3760, doi:10.1002/hyp.9925.

Dorigo, W. A., and Coauthors, 2014: Evaluation of the ESA CCI soil moisture product using ground-based observations. *Remote Sens. Environ.*, **162**, 380–395, doi:10.1016/j.rse.2014.07.023.

Dorigo, W., R. de Jeu, D. Chung, R. Parinussa, Y. Liu, W. Wagner, and D. Fernández-Prieto, 2012: Evaluating global trends (1988-2010) in harmonized multi-satellite surface soil moisture. *Geophys. Res. Lett.*, **39**, L18405, doi:10.1029/2012GL052988.

Dorigo, W., and Coauthors, 2014: Soil moisture [in "State of the Climate in 2013"]. *Bull. Amer. Meteor. Soc.*, **95**(7), S25–S26.

Griesfeller, A., and Coauthors, 2013: Evaluation of SMOS and ASCAT soil moisture products over Norway using ground-based in situ observations. *EGU General Assembly 2013*. Retrieved from http://adsabs.harvard.edu/abs/2013EGUGA..15.3897G

Hirschi, M., B. Mueller, W. Dorigo, and S. I. Seneviratne, 2014: Using remotely sensed soil moisture for land–atmosphere coupling diagnostics: The role of surface vs. root-zone soil moisture variability. *Remote Sens. Environ.*, **154**, 246–252, doi:10.1016/j.rse.2014.08.030.

Hollmann, R., and Coauthors, 2013: The ESA Climate Change Initiative: Satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, **94**, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Holmes, T. R. H., W. T. Crow, and R. A. M. de Jeu, 2014: Leveraging microwave polarization information for the calibration of a land data assimilation system. *Geophys. Res. Lett.*, 41, 8879–8886, doi:10.1002/2014GL061991.

Kim, S., Y. Y. Liu, F M. Johnson, R. M. Parinussa, and A. Sharma, 2015: A global comparison of alternate AMSR2 soil moisture products: Why do they differ? *Remote Sens. Environ.*, **161**, 43–62, doi:10.1016/j.rse.2015.02.002.

Lahoz, W. A., and G. J. M. De Lannoy, 2014: Closing the gaps in our knowledge of the hydrological cycle over land: Conceptual problems. *Surv. Geophys.*, **35**, 626–666, doi:10.1007/s10712-013-9221-7

Lahoz, W. A., and P. Schneider, 2014: Data assimilation: Making sense of Earth observation. *Frontiers Environ. Sci.*, **2**, 16, doi:10.3389/fenvs.2014.00016.

Liu, Y. Y., and Coauthors, 2012: Trend-preserving blending of passive and active microwave soil moisture retrievals. *Remote Sens. Environ.*, **123**, 280–297, doi:10.1016/j.rse.2012.03.014.

Liu, Y. Y., and Coauthors, 2011: Developing an improved soil moisture dataset by blending passive and active microwave satellite-based retrievals. *Hydrol. Earth Syst. Sci.*, **15**, 425–436, doi:10.5194/hess-15-425-2011.

Liu, Y. Y., A. I. J. M. van Dijk, R. A. M. de Jeu, J. G. Canadell, M. F. McCabe, J. P. Evans, and G. Wang, 2015: Recent reversal in loss of global terrestrial biomass. *Nature Climate Change*, **5**, 470–474, doi:10.1038/nclimate2581.

Loew, A., T. Stacke, W. Dorigo, R. de Jeu, and S. Hagemann, 2013: Potential and limitations of multidecadal satellite soil moisture observations for selected climate model evaluation studies. *Hydrol. Earth Syst. Sci.*, **17**, 3523–3542, doi:10.5194/hess-17-3523-2013.

Miralles, D. G., and Coauthors, 2013: El Niño–La Niña cycle and recent trends in continental evaporation. *Nature Climate Change*, **4**, 122–126, doi:10.1038/nclimate2068.

Muñoz, A. A., and Coauthors, 2013: Patterns and drivers of *Araucaria araucana* forest growth along a biophysical gradient in the northern Patagonian Andes: Linking tree rings with satellite observations of soil moisture. *Austral Ecol*., **39**, 158–169, doi:10.1111/aec.12054.

Parinussa, R. M., 2013: Uncertainty characterisation in remotely sensed soil moisture. Ph.D. thesis, VU University Amsterdam. Retrieved from http://dare.ubvu.vu.nl/bitstream/handle/1871/41480/dissertation.pdf?sequence=1.

Parinussa, R. M., T. R. H. Holmes, and R. A. M. de Jeu, 2012: Soil moisture retrievals from the WindSat spaceborne polarimetric microwave radiometer. *IEEE Trans. Geosci. Remote Sens*., **50**, 2683–2694, doi:10.1109/TGRS.2011.2174643.

Parinussa, R. M. and Coauthors, 2013: Soil moisture [in "State of the Climate in 2012"]. *Bull. Amer. Meteor. Soc*., **94**(8), S24–S25.

Parinussa, R. M., T. R. H. Holmes, N. Wanders, W. A. Dorigo, and R. A. M. de Jeu, 2014: A preliminary study towards consistent soil moisture from AMSR2. *J. Hydrometeor*., **16**, 934–947, doi:10.1175/JHM-D-13-0200.1.

Parinussa, R. M., and Coauthors, 2014: Global surface soil moisture from the Microwave Radiation Imager onboard the Fengyun-3B satellite. *Int. J. Remote Sens*., **35**, 7007–7029, doi:10.1080/01431161.2014.960622.

Parinussa, R. M., M. T. Yilmaz, M. C. Anderson, C. R. Hain, and R. A. M. de Jeu, 2013: An intercomparison of remotely sensed soil moisture products at various spatial scales over the Iberian Peninsula. *Hydrolog. Proc*., 28, 4865–4876, doi:10.1002/hyp.9975.

Szczypta, C., J.-C. Calvet, F. Maignan, W. Dorigo, F. Baret, and P. Ciais, 2014: Suitability of modelled and remotely sensed essential climate variables for monitoring Euro-Mediterranean droughts. *Geosci. Model Develop*., **7**, 931–946. doi:10.5194/gmd-7-931-2014.

Taylor, C. M., R. A. M. de Jeu, F. Guichard, P. P. Harris, and W. A. Dorigo, 2012: Afternoon rain more likely over drier soils. *Nature*, **489**, 423–426, doi:10.1038/nature11377.

Tramblay, Y., E. Amoussou, W. Dorigo, and G. Mahé, 2014: Flood risk under future climate in data sparse regions: Linking extreme value models and flood generating processes. *J. Hydrol*., **519**, 549–558, doi:10.1016/j.jhydrol.2014.07.052.

Wagner, W., W. Dorigo, R. de Jeu, D. Fernandez, J. Benveniste, E. Haas, and M. Ertl, 2012: Fusion of active and passive microwave observations to create an essential climate variable data record on soil moisture. *ISPRS Ann. Photogram. Remote Sens. Spatial Info. Sci*., **I-7**, 315–321, doi:10.5194/isprsannals-I-7-315-2012.

Wagner, W., C. Paulik, and W. Dorigo, 2012: The use of Earth observation satellites for soil moisture monitoring [in WMO statement on the status of the global climate in 2012]. WMO-No. 1108.

5.5.4.2 GCOS/CEOS Action T14; SS: T.11

Action: Develop Global Terrestrial Network for Soil Moisture (GTN-SM).
Who: Parties' national services and research programmes, through IGWCO, GEWEX and TOPC in collaboration with space agencies.
Time frame: 2014.
Performance indicator: Fully functional GTN-SM with a set of *in situ* observations (possibly collocated with reference network, cf. T3), with standard measurement protocol and data quality and archiving procedures.
Annual Cost Implications: 1-10M US$ (40% in non-Annex-I Parties).

2015 Update:

- ISMN was set up in 2009 and has been running successfully since then
- Currently, almost 50 networks participate, providing more than 7000 soil moisture data sets from almost 2000 sites worldwide
- The ISMN has been migrated to https://ismn.geo.tuwien.ac.at/
- Data archiving and quality control procedures are mature and fully automated
- The ISMN has been integrated in the Global Terrestrial Network – Hydrology (GTN-H) of the Group on Earth Observations/Integrated Global Water Cycle Observations (GEO/IGWCO) theme in June 2013
- Funding for operations have been provided by ESA and may e xtend into 2018. After this date the funding situation is unclear. To keep ISMN operational in a basic form, a minimum of 100 kEUR/year is needed.
- Surveys sent out to data providers and users reveal that both parties are very satisfied and see an urgent need to continue the ISMN.
- Standard measurement protocol still needs to be developed and agreed upon.

5.5.5.1 GCOS/CEOS Action T16; SS: T.2

Action: Obtain integrated analyses of snow cover over both hemispheres.
Who: Space agencies and research agencies in cooperation with WMO GCW and CliC, with advice from TOPC, AOPC and IACS.
Time-Frame: Continuous.
Performance Indicator: Availability of snow-cover products for both hemispheres.
Annual Cost Implications: 1-10M US$ (Mainly by Annex-I Parties).

2015 Update

Global 24 km snow cover estimates for the northern hemisphere using the Rutgers method are now operational through the NOAA Climate Data Records program. There are no routine products on snow cover for the southern hemisphere.

The ESA funded *Satellite Snow Product Intercomparison and Evaluation Experiment (SnowPEx)* intercompars and validates hemispheric and global satellite snow products for estimation of temporal trends of the seasonal snow cover and assessing their accuracy. More than 15 snow extent products from optical satellites and snow water equivalent products from passive microwave data are participating in SnowPEx. At the 2nd International Satellite Snow Product Intercomparison Workshop to be held in Boulder, Colo. (USA), from 14-16 September 2015, first intercomparison results will presented and discussed.

5.5.6.1 GCOS/CEOS Action T17; SS: T.3.1, T.3.2

Action: Maintain current glacier observing sites and add additional sites and infrastructure in data-sparse regions, including South America, Africa, the Himalayas, and New Zealand; attribute quality levels to long-term mass balance measurements; complete satellite-based glacier inventories in key areas.
Who: Parties' national services and agencies coordinated by GTN-G partners, WGMS, GLIMS, and NSIDC.
Time-Frame: Continuing, new sites by 2015.
Performance Indicator: Completeness of database held at NSIDC from WGMS and GLIMS.
Annual Cost Implications: 10–30M US$ (80% in non-Annex-I Parties).

2015 Update

Glaciers_cci is providing an important contribution on mapping glacier and ice-cap areas in key regions, complemented by ice flow and elevation change observations. This effort is focussed on completing the databases on global glaciers in coordination with global efforts though WGMS/GLIMS and the Randolph Glacier Inventory.

Glacier area, elevation change and ice flow velocity are derived using a variety of sensors: high resolution optical, altimeters (ICESat, Cryosat) and SAR. The project has developed online tools for processing optical and microwave observations of glacier flow, and for elevation change using DEM differencing.
Glaciers_cci made major contributions in Norway, Greenland, Alaska, Himalaya, Pamir, Tien Shan, South Georgia, the Andes and Svalbard.

See http://www.esa-glaciers-cci.org for additional information

References:

Allison, I., W. Colgan, M. King, and F. Paul, 2015: Ice sheets, glaciers and sea level. In *Snow and Ice-Related Hazards, Risks, and Disasters*, W. Haeberli and C. Whiteman (Eds.), Elsevier, pp. 714–748.

Bhambri, R., T. Bolch, P. Kawishwar, D.P. Dobhal, D. Srivastava, and B. Pratap, 2013: Heterogeneity in glacier response in the upper Shyok valley, northeast Karakoram. *The Cryosphere*, **7**, 1385–1398, doi:10.5194/tc-7-1385-2013.

Bolch, T., and Coauthors, 2012: The state and fate of Himalayan glaciers. *Science*, **336**, 310–314, doi:10.1126/science.1215828.

Bolch, T., T. Pieczonka, and D.I. Benn, 2011: Multi-decadal mass loss of glaciers in the Everest area (Nepal Himalaya) derived from stereo imagery. *The Cryosphere*, **5**, 349–358, doi:10.5194/tc-5-349-2011.

Bolch, T., L. Sandberg Sørensen, S.B. Simonsen, N. Mölg, H. Machguth, P. Rastner, and F. Paul, 2013: Mass loss of Greenland's glaciers and ice caps 2003-2008 revealed from ICESat laser altimetry data. *Geophys. Res. Lett.*, **40**, 875–881, doi:10.1002/grl.50270.

Debella-Gilo, M., and A. Kääb, 2012a: Locally adaptive template sizes for matching repeat images of Earth surface mass movements. *ISPRS J. Photogram. Remote Sens.*, **69**, 10–28, doi:10.1016/j.isprsjprs.2012.02.002.

Debella-Gilo, M., and A. Kääb, 2012b: Measurement of surface displacement and deformation of mass movements using least squares matching of repeat high resolution satellite and aerial images. *Remote Sens.*, **4**, 43–67, doi:10.3390/rs4010043.

Frey, H., and Coauthors, 2013: Ice volume estimates for the Himalaya–Karakoram region: Evaluating different methods. *The Cryosphere Disc.*, **7**, 4813–4854, doi:10.5194/tcd-7-4813-2013.

Gardelle, J., E. Berthier, Y. Arnaud, and A. Kääb, 2013: Region-wide glacier mass balances over the Pamir-Karakoram-Himalaya during 1999–2011. *The Cryosphere*, **7**, 1263–1286, doi:10.5194/tc-7-1263-2013.

Gardner, A. S., and Coauthors, 2013: A reconciled estimate of glacier contributions to sea level rise: 2003 to 2009. *Science*, **340**, 852–857, doi:10.1126/science.1234532.

Heid, T., and A. Kääb, 2012a:. Evaluation of existing image matching methods for deriving glacier surface displacements globally from optical satellite imagery. *Remote Sens. Environ.*, **118**, 339–355, doi:10.1016/j.rse.2011.11.024.

Heid, T., and A. Kääb, 2012b: Repeat optical satellite images reveal widespread and long term decrease in land-terminating glacier speeds. *The Cryosphere*, **6**, 467–478, doi:10.5194/tc-6-467-2012.

Hollmann, R., and Coauthors, 2013: The ESA Climate Change Initiative: Satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, **94**, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Kääb, A., E. Berthier, C. Nuth, J. Gardelle, and Y. Arnaud, 2012: Contrasting patterns of early twenty-first-century glacier mass change in the Himalayas. *Nature*, **488**, 495–498, doi:10.1038/nature11324.

Kargel, J. S., G. J. Leonard, M. P. Bishop, A Kääb, and B. H. Raup, Eds., 2014: *Global Land Ice Measurements from Space*, Springer, 876 pp., doi:10.1007/978-3-540-79818-7.

Leclercq, P. W., A. Weidick, F. Paul, T. Bolch, M. Citterio, and J. Oerlemans, 2012: Brief communication "Historical glacier length changes in West Greenland." *The Cryosphere*, **6**, 1339–1343, doi:10.5194/tc-6-1339-2012.

Marzeion, B., J. G. Cogley, K. Richter, and D. Parkes, 2014: Attribution of global glacier mass loss to anthropogenic and natural causes. *Science*, **345**, 919–921, doi:10.1126/science.1254702.

Neckel, N., J. Kropáček, T. Bolch, and V. Hochschild, 2014: Glacier mass changes on the Tibetan Plateau 2003–2009 derived from ICESat laser altimetry measurements. *Environ. Res. Lett.*, **9**, 014009, doi:10.1088/1748-9326/9/1/014009.

Nuth, C., and A. Kääb, 2011: Co-registration and bias corrections of satellite elevation data sets for quantifying glacier thickness change. *The Cryosphere*, **5**, 271–290, doi:10.5194/tc-5-271-2011.

Nuth, C., and Coauthors, 2013: Decadal changes from a multi-temporal glacier inventory of Svalbard. *The Cryosphere*, **7**, 1603–1621, doi:10.5194/tc-7-1603-2013.

Nuth, C., T. V. Schuler, J. Kohler, B. Altena, and J. O. Hagen, 2012: Estimating the long-term calving flux of Kronebreen, Svalbard from geodetic elevation changes and mass-balance modelling. *J. Glaciol*.. 58, 119–133, doi:10.3189/2012JoG11J036.

Paul, F., 2011: Sea-level rise: Melting glaciers and ice caps. *Nature Geosci*., **4**, 71–72, doi:10.1038/ngeo1074.

Paul, F., and Coauthors, 2013: On the accuracy of glacier outlines derived from remote-sensing data. *Ann. Glaciol*., **54**, 171–182 , doi:10.3189/2013AoG63A296.

Paul, F., and Coauthors, 2013: The Glaciers Climate Change Initiative: Algorithms for creating glacier area, elevation change and velocity products. *Remote Sens. Environ*., **162**, 408–426, doi:10.1016/j.rse.2013.07.043.

Paul, F., T. Bolch, A. Kaab, T. Nagler, A. Shepherd, and T. Strozzi, 2012: Satellite-based glacier monitoring in the ESA project Glaciers_cci. In *2012 IEEE Int. Geosci. Remote Sens. Symp*., IEEE, pp. 3222–3225, doi:10.1109/IGARSS.2012.6350738.

Paul, F., and N. Mölg, 2014: Hasty retreat of glaciers in northern Patagonia from 1985 to 2011. *J. Glaciol*., **60**, 1033–1043, doi: 10.3189/2014JoG14J104.

Pellicciotti, F., C. Stephan, E. Miles, S. Herreid, W. Immerzeel, and T. Bolch, 2014: Mass-balance changes of the debris-covered glaciers in the Langtang Himal, Nepal, between 1974 and 1999. *J. Glaciol*., **61**, 373–386, doi:10.3189/2015JoG13J237.

Pfeffer, W., and Coauthors, 2014: The Randolph Glacier Inventory: A globally complete inventory of glaciers. *J. Glaciol*., **60**, 537–552, doi:10.3189/2014JoG13J176.

Pieczonka, T., T. Bolch, W. Junfeng, and L. Shiyin, 2013: Heterogeneous mass loss of glaciers in the Aksu-Tarim Catchment (Central Tien Shan) revealed by 1976 KH-9 Hexagon and 2009 SPOT-5 stereo imagery. *Remote Sens. Environ*., **130**, 233–244, doi:10.1016/j.rse.2012.11.020.

Rastner, P., T. Bolch, N. Mölg, H. Machguth, and F. Paul, 2012: The first complete glacier inventory for the whole of Greenland. *The Cryosphere Disc*., **6**, 2399–2436, doi:10.5194/tcd-6-2399-2012.

Rastner, P., T. Bolch, C. Notarnicola, and F. Paul, 2013: A comparison of pixel- and object-based glacier classification with optical satellite images. *IEEE J. Sel. Topics Appl. Earth Obs. Remote Sens*., **7**, 853–862, doi:10.1109/JSTARS.2013.2274668.

Rastner, P., Bolch, T., Notarnicola, C., & Paul, F. (2013). A Comparison of Pixel- and Object-Based Glacier Classification With Optical Satellite Images. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, PP(99), 1–10. doi:10.1109/JSTARS.2013.2274668

5.5.7.1 GCOS/CEOS Action T20; SS: T.4

Action: Ensure continuity of laser, altimetry, and gravity satellite missions adequate to monitor ice masses over decadal timeframes.
Who: Space agencies, in cooperation with WCRP CliC and TOPC.
Time-Frame: New sensors to be launched: 10-30 years.
Performance Indicator: Appropriate follow-on missions agreed.
Annual Cost Implications: 30-100M US$ (Mainly by Annex-I Parties).

2015 Update

Ice_sheets_cci consists of two projects covering the Greenland and Antarctic ice sheets respectively. Both projects provide the same set of ECV parameters:

- Surface Elevation Change (1991-2017) over the whole ice sheets from radar altimeters on ERS-1, ERS-2, Envisat, ICESat, Cryosat, AltiKa and Sentinel-3.
- Ice Velocity from ERS-1, ERS-2, Envisat ASAR, Sentinel-1, Radarsat, Palsar and TerraSAR-X (1991-2017)
  - West Antarctic Ice Sheet and Antarctic Peninsula
  - Greenland ice sheet (2014-2017) from Sentinel-1 SAR
  - Main Greenland glaciers (1991-2017)
- Grounding Line Location from multi-sensor InSAR - ERS-1, ERS-2, Envisat, Sentinel-1, Palsar and TerraSAR-X (1991-2017)
- GRACE-derived mass balance (2002-present)
- Calving Front Location for major outlet glaciers from ERS, Envisat, Sentinel-1 and Sentinel-2. (1991-2017)

Consistency with Glaciers_cci is ensured to avoid double-counting of glaciers, and to ensure all areas of ice-loss are covered.
The projects founded, coordinated and participated in the international Ice Sheet Mass Balance Intercomparison Exercise (IMBIE), and the IPCC Coordinating lead author on ice sheets is closely involved as Chair of the projects' Climate Research Groups.
See: http://www.esa-icesheets-cci.org

Annual cost: seems low. ICESat-2 is $700M, NISAR will be $1.2 B, GRACE follow on ~ $300M

For InSAR, please quote the NASA ISRO SAR (NISAR) mission which was recently made official between India and the US, and will be the first InSAR dedicated mission looking at ice sheets.

For future/current missions:

The EU is providing access to Sentinel-1a and 1b (InSAR), which are tremendously useful.

CSA will launch RADARSAT-3 and a RADARSAT constellation (I think R-3 will be part of that).

There is GRACE follow on but also GRACE-2.

Landsat-8 is useful for ice motion (when no cloud).

The EU will launch Sentinel-3 (altimetry).

References

Hollmann, R., and Coauthors, 2013: The ESA Climate Change Initiative: Satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, **94**, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Levinsen, J. F., and Coauthors, 2013: ESA's Ice Sheets CCI: Validation and inter-comparison of surface elevation changes derived from laser and radar altimetry over Jakobshavn Isbræ, Greenland – Round Robin results. *The Cryosphere Disc*., **7**, 5433–5460, doi:10.5194/tcd-7-5433-2013.

Shepherd, A., and Coauthors, 2012: A reconciled estimate of ice-sheet mass balance. *Science*, **338**, 1183–1189, doi:10.1126/science.1228102.

5.5.8.1 GCOS/CEOS Action T23; SS: T.12

Action: Implement operational mapping of seasonal soil freeze/thaw through an international initiative for monitoring seasonally-frozen ground in non-permafrost regions.
Who: Parties, space agencies, national services, and NSIDC, with guidance from International Permafrost Association, the IGOS Cryosphere Theme team, and WMO GCW.
Time-Frame: Complete by 2015.
Performance Indicator: Number and quality of mapping products published.
Annual Cost Implications: 1-10M US$ (10% in non-Annex-I Parties).

2015 Update

Monthly mean maps of freeze/thaw continue to be produced routinely from AMSR data. NASA successfully launched the Soil Moisture Active Passive (SMAP) on 31 January 2015. NASA plans to produce a daily classification of freeze/thaw state for land areas north of 45°N derived from the SMAP high-resolution radar output to 3 km polar and global EASE grids.

5.5.9.1 GCOS/CEOS Action T24; SS: T.5

Action: Obtain, archive, and make available *in situ* calibration/validation measurements and collocated albedo products from all space agencies generating such products; promote benchmarking activities to assess the quality and reliability of albedo products.
Who: Space agencies in cooperation with CEOS WGCV.
Time-Frame: Full benchmarking/intercomparison by 2012.
Performance Indicator: Publication of inter-comparison/validation reports.
Annual Cost Implications: 1-10M US$ (20% in non-Annex-I Parties).

2015 Update

Sensor-specific validation efforts continued during 2011-2015. Due to a lack of dedicated funding, the planned activities for intercomparison and validation across albedo products and the publication of fiducial reference data set based on in-situ networks are delayed. The Land Product Validation Subgroup of CEOS WGCV has updated and published validation and intercomparison information at the end of 2014 available on the Land Product Validation web site http://lpvs.gsfc.nasa.gov/. The validation and intercomparison protocol is under development.

5.5.9.2 GCOS/CEOS Action T25; SS: T.5

Action: Implement globally coordinated and linked data processing to retrieve land surface albedo from a range of sensors on a daily and global basis using both archived and current Earth Observation systems.
Who: Space agencies, through the CGMS and WMO Space Programme.
Time-Frame: Reprocess archived data by 2012, then generate continuously.
Performance Indicator: Completeness of archive.
Annual Cost Implications: 1-10M US$ (Mainly by Annex-I Parties)

2015 Update

Two SCOPE-CM projects are ongoing, SCM-02 (Surface albedo LEO) and SCM-03 (Surface albedo GEO) with the aim of evaluating and producing Climate Data Records (CDR) for surface albedo.

a) Surface albedo CDR from Geostationary satellites (SCM-03)

Land surface albedo is a key forcing parameter for the climate system controlling the radiative energy budget. It is the Global Climate Observing System (GCOS) terrestrial Essential Climate Variable (ECV) product T.5 that is described including product requirements in GCOS-154, thus, its monitoring is of primary importance for an understanding of the climate system. Its value changes in space and time, depending on both natural processes (vegetation growth, rain and snowfall and snow melting, wildfires, etc.) and human activities (forestation and deforestation, harvesting crops, anthropogenic fires, etc.). Observations acquired by geostationary satellites have the advantages of offering both a long-term dataset and an angular sampling of the surface as well as providing diurnal sampling of key parameters influencing the retrieval such as cloud cover and aerosol load. The project objective is the generation of a land surface albedo Climate Data Record (CDR) covering the Earth surface seen by geostationary satellites (Polar Regions are not included) for a time window of approximately 30 years. The project aims at a product that includes Level 2 (at the native instrument resolution) and Level 3 (at coarse resolution between 0.25 and 1.0 degree) surface albedo data records to be utilized in climate science and climate services.

Phase 1 (2008-2012)

The SCOPE-CM Phase 1 focused on the establishment of a coordinated network of space agencies and organizations. The main task during this phase is the creation of interagency partnerships and the establishment of the network, for which five pilot projects have been started. During this phase the involved agencies have demonstrated that the current approach is feasible. The involved scientists have all the necessary skills to continue the work including updates to the retrieval system. The team spirit during the unfunded activities of phase 1 was demonstrated by a joint publication in the *Bulletin of the American Meteorological Society* (Lattanzio et al. 2013). During this phase a first processing of the data archives in EUMETSAT, JMA and NOAA has been performed to check the feasibility of such a federated activity.

Phase 2 (2012-2018)

The SCOPE-CM Implementation Plan (SCOPE-CM 2014) was revisited in 2012 and the Land surface albedo from geostationary satellites (LAGS) project has been accepted in 2014. The first objectives are the quality improvement, in particular in terms of residual cloud contamination removal, and a homogenization of the ancillary input information (calibration and NWP data) among the 3 agencies. The need to tackle these issues was a clear outcome of the first phase. The next Level 2 reprocessing campaign is foreseen for 2016. Following the success of such an activity a near-global Level 3 product will be generated and distributed. The project team is confident that the resulting CDR will contribute to climate studies answering questions such as on monsoon decadal scale variability. It will further contribute to the evaluation of quality of climate model simulations by entering the Obs4MIPs initiative and to direct estimates of global surface energy budget.

b) Surface albedo CDR from polar-orbiting satellites (SCM-02)

The geostationary efforts are being augmented by a second SCOPE-CM effort, SCM-02, with contributions by the Finnish Meteorological Institute (FMI), University of Massachusetts (Boston), and EUMETSAT. The aim of this pilot project is to derive a roadmap for estimation of surface albedo using data from several satellite intruments thus benefitting from increased temporal sampling. This method is demonstrated using AVHRR and MODIS images. The quality aims at the GCOS requirements (http://www.scope-cm.org/projects/scm-02/).

Lattanzio A., J. Schulz, J. Matthews, A. Okuyama, B. Theodore, J. J. Bates, K. R. Knapp, Y. Kosaka, and L. Schüller, 2013: Land surface albedo from geostationary satellites: A multi-agency collaboration within SCOPE-CM. *Bull. Amer. Meteor. Soc.*, **94**, 205–214, doi:10.1175/BAMS-D-11-00230.1.

SCOPE-CM, 2014: http://www.scope-cm.org/wpcms/wp-content/uploads/2014/01/SCOPE-CM_Phase-2-Implementation-Plan.pdf

5.5.10.1 GCOS/CEOS Action T27; SS: T.6.1 (Moderate-resolution maps of land-cover type) and T.6.2 (High-resolution maps of land-cover type)

Action: Generate annual products documenting global land-cover characteristics and dynamics at resolutions between 250 m and 1 km, according to internationally-agreed standards and accompanied by statistical descriptions of their accuracy.
Who: Parties' national services, research institutes and space agencies in collaboration with GLCN and GOFC-GOLD research partners and the Global Forest Observations Initiative (GFOI) R&D and Methods and Guidance components, and the CEOS Space Data Coordination Group for GFOI.
Time-Frame: By 2011, then continuously.
Performance Indicator: Dataset availability.
Annual Cost Implications: 1-10M US$ (20% in non-Annex-I Parties).

2015 Update

VIIRS land products are currently under development and initial products may be available in late 2015. See additional information at following the Action, GCOS/CEOS Action T28, SS: T.12.

The Land cover cci project performed optical (MERIS, SPOT-VGT, Proba-V, AVHRR) and SAR (ASAR) image classification, in consultation with international partners, IGBP, GOFC-GOLD, FAO, EEA and JRC, the Land_Cover_cci, to provide:

- Global moderate resolution (300m) land cover maps for epochs: 1990, 2000, 2005, 2010, 2015
- Land cover seasonality characterisation: vegetation greenness, snow and burned area
- Global map of permanent water bodies

Higher resolution land cover mapping is being demonstrated over Africa with Sentinel-2 and Landsat-8 data.
Products are supplemented by a tool for subsetting, re-projecting and re-sampling the products for use in climate modelling.
See: http://www.esa-landcover-cci.org

References:

André, C., C. Ottlé, A. Royer, and F. Maignan, 2015: Land surface temperature retrieval over circumpolar Arctic using SSM/I–SSMIS and MODIS data. *Remote Sens. Environ.*, **162**, 1–10, doi:10.1016/j.rse.2015.01.028.

Bontemps, S., and Coauthors, 2012: Revisiting land cover observation to address the needs of the climate modeling community. *Biogeosciences*, **9**, 2145–2157, doi:10.5194/bg-9-2145-2012.

Gamba, P., and G. Lisini, 2013: Fast and efficient urban extent extraction using ASAR wide swath mode data. *IEEE J. Sel. Topics Appl. Earth Obs. Remote Sens.*, **6**, 2184–2195. doi:10.1109/JSTARS.2012.2235410.

Hollmann, R., and Coauthors, 2013: The ESA Climate Change Initiative: satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, 94, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Ottlé, C., J. Lescure, F. Maignan, B. Poulter, T. Wang, and N. Delbart, 2013: Use of various remote sensing land cover products for PFT mapping over Siberia. *Earth Sys. Sci. Data Disc.*, **6**, 255–296, doi:10.5194/essdd-6-255-2013.

Poulter, B., P. Ciais, E. Hodson, H. Lischke, F. Maignan, S. Plummer, and N. E.Zimmermann, 2011: Plant functional type mapping for earth system models. *Geosci. Model Develop.*, **4**, 993–1010, doi:10.5194/gmd-4-993-2011.

Poulter, B., and Coauthors, 2015: Plant functional type classification for Earth system models: Results from the European Space Agency's Land Cover Climate Change Initiative. *Geosci. Model Develop. Disc.*, **8**, 429–462, doi:10.5194/gmdd-8-429-2015.

Santoro, M., and U. Wegmuller, 2014: Multi-temporal synthetic aperture radar metrics applied to map open water bodies. *IEEE J. Sel. Topics Appl. Earth Obs. Remote Sens.*, **7**, 3225–3238, doi:10.1109/JSTARS.2013.2289301.

5.5.10.2 GCOS/CEOS Action T28; SS: T.12

Action: Generate maps documenting global land cover based on continuous 10-30 m land surface imagery every 5 years, according to internationally-agreed standards and accompanied by statistical descriptions of their accuracy.
Who: Space agencies, in cooperation with GCOS, GTOS, GOFC-GOLD, GLCN, and other members of CEOS.
Time-Frame: First by 2012, then continuously.
Performance Indicator: Availability of operational plans, funding mechanisms, eventually maps.
Annual Cost Implications: 10-30M US$ (20% in non-Annex-I Parties).

2015 Update

Key activities:

- Peer review of product strategy (completed)
- Develop land cover fraction 2010 continental prototype (completed 2014)
- Completion of a global land cover validation data set (completed 2015)
- Completion of validated global land cover fractions for 2000-2010 (in progress)
- Completion of validated global land cover types for 2010 (in progress)
- Transition into operational annual monitoring (TBD)
- Improve global 30m imagery data set coverage (TBD)

The USGS, in collaboration with the University of Maryland and other partners, has completed the first Global datasets comprised of per tree cover, percent water, and percent barren land. A validation dataset comprised of 500+ globally distributed sites has been compiled based on high-resolution commercial satellite imagery and from which corresponding percent cover (tree, water, barren) and thematic classifications have been developed. The validation of the circa 2010 datasets is underway and results will be submitted for peer reviewed journal publication.

5.5.11.1 GCOS/CEOS Action T29; SS: T.7

Action: Establish a calibration/validation network of *in situ* reference sites for FAPAR and LAI
Who: Parties' national and regional research centres, in cooperation with space agencies coordinated by CEOS WGCV, GCOS and GTOS.
Time-Frame: Network operational by 2012.
Performance Indicator: Percentage of sites reporting.
Annual Cost Implications: 1-10M US$ (40% in non-Annex-I Parties).

2015 Update

The Land Product Validation Subgroup of the CEOS WGCV (LPV) has taken on a coordination role to establish fiducial reference data in collaboration with long-term in-situ networks for fAPAR and LAI. The LPV focus area for fAPAR and LAI are in contact with in-situ networks (e.g., NEON, ICOS) to coordinate field sampling protocols. A fAPAR workshop was held in

2014 to discuss details of a fAPAR intercomparison and validation protocol and field instrument set-up and sampling. In 2015, a few sites were instrumented and with calibrated PAR sensors that will allow for the generation of high-quality fAPAR reference data. However, the number of validation sites remains limited (see http://lpvs.gsfc.nasa.gov/Fpar_home.html).

Work on the generation of LAI in-situ reference data has been ongoing. A compiled reference data set has been extended recently for crop- and grassland sites in the framework of the EU Framework Programme 7 project ImagineS (http://fp7-imagines.eu) . It is planned to make these data available through the PLIVE platform.

5.5.12.1 GCOS/CEOS Action T30; SS: T.7

Action: Evaluate the various LAI satellite products and benchmark them against *in situ* measurements to arrive at an agreed operational product.
Who: Parties' national and regional research centres, in cooperation with space agencies and CEOS WGCV, TOPC, and GTOS.
Time-Frame: Benchmark by 2012.
Performance Indicator: Agreement on operational product.
Annual Cost Implications: 1-10M US$ (10% in non-Annex-I Parties).

2015 Update

Completion or significant progress of all planned key activities related to this action has been achieved. The Land Product Validation subgroup of the CEOS Working Group on Calibration and Validation has coordinated the implementation pof an on-line validation system, supported by ESA (Weiss et al., 2014). The subgroup is coordinating with several long-term in-situ networks to improve the quantity and quality of validation data, for example by reviewing field sampling protocols (e.g., ICOS, NEON). Most importantly, the LPV subgroup compiled and distributed a community-reviewed best practices document for LAI intercomparison and validation. This document is referenced with a DOI (doi:10.5067/doc/ceoswgcv/lpv/lai.002). For more information see http://lpvs.gsfc.nasa.gov/LAI_home.html.

5.5.12.2 GCOS/CEOS Action T31; SS: T.7 (fAPAR) and T.8 (LAI)

Action: Operationalize the generation of FAPAR and LAI products as gridded global products at spatial resolution of 2 km or better over time periods as long as possible.
Who: Space agencies, coordinated through CEOS WGCV, with advice from GCOS and GTOS.
Time-Frame: 2012.
Performance Indicator: One or more countries or operational data providers accept the charge of generating, maintaining, and distributing global FAPAR products.
Annual Cost Implications: 10-30M US$ (10% in non-Annex-I Parties).

2015 Update

Operational product generation has commenced through NOAA and EUMETSAT. For example, NOAA's Climate Data Records Program has transitioned the production of LAI and fAPAR to operations (http://www.ncdc.noaa.gov/cdr/operationalcdrs.html). The records are global on a 0.05 by 0.05 degree grid and are produced daily from 1981-present. These records are also routinely updated and full documentation is available. However, to date community agreed specifications of uncertainty, reconciliation of algorithms and ancillary data have not been achieved for LAI and all contributing archives have not been therefore reprocessed to date.

5.5.13.1 GCOS/CEOS Action T32; SS: N/A

Action: Develop demonstration datasets of above ground biomass across all biomes.
Who: Parties, space agencies, national institutes, research organizations, FAO in association with GTOS, TOPC, the GOFC-GOLD Biomass Working Group, and GFOI.
Time frame: 2012.
Performance Indicator: Availability of global gridded estimates of above ground biomass and associated carbon content.
Annual Cost Implications: 1-10M US$ (20% in non-Annex-I Parties).

2015 Update

CEOS has established an *ad hoc* Space Data Coordination Group (SDCG) for the Global Forest Observations Initiative (GFOI) to support developing countries in setting up national forest monitoring systems. This supports reporting in the REDD+ context and includes the production of above ground biomass data sets. Details can be found at http://gfoi.org/.

5.5.14.1 GCOS/CEOS Action T34; SS: N/A

Action: Develop globally gri**d**ded estimates of terrestrial carbon flux from *in situ* observations and satellite products and assimilation/inversions models.
Who: Reanalysis centres and research organisations, in association with national institutes, space agencies, and FAO/GTOS (TCO and TOPC).
Time Frame: 2014-2019.
Performance indicator: Availability of data assimilation systems and global time series of maps of various terrestrial components of carbon exchange (e.g., Gross Primary Production (GPP), Net Ecosystem Production (NEP), and Net Biome Production (NBP)).
Annual Cost Implications: 10-30M US$ (Mainly by Annex-I Parties).

2015 Update

CEOS has published a Strategy for Carbon Observations from Space (http://ceos.org/document_management/Publications/WGClimate_CEOS-Strategy-for-Carbon-

Observations-from-Space_Apr2014.pdf) and is implementing a number of the actions identified in the strategy report through the appropriate Virtual Constallations and Working Groups.

5.5.15.1 GCOS/CEOS Action T35; SS: T.10

Action: Reanalyse the historical fire disturbance satellite data (1982 to present).
Who: Space agencies, working with research groups coordinated by GOFC-GOLD.
Time-Frame: By 2012.
Performance Indicator: Establishment of a consistent dataset, including the globally available 1 km AVHRR data record.
Annual Cost Implications: 1-10M US$ (Mainly by Annex-I Parties).

2015 Update

This action was discussed at the 2014 GOFC-GOLD Fire Implementation Team meeting in College Park, MD, and it was agreed it was more beneficial for stakeholders to focus on ensuring future continuity with the MODIS data record. The rescue of the 1-km AVHRR data record is overarching issue. Agencies should make a coordinated data rescue effort (including HRPT from various DB operators), which would be the pre-requisite for generating a 1km-based fire data record. There have been some previous efforts, such as using USGS and NOAA archives, but none of these appear to be complete.

The Fire_cci project is developing monthly global burnt area maps prototyped on the period 1981-2015 (AVHRR, MERIS, VGT, Proba-V, MODIS, Sentinel-3, as well as Sentinel-2 for small fires in Africa). In perennially cloud covered areas complementary information derived from SAR is included.
To advance on product quality it a unique validation database has been built consisting of high resolution optical satellite images collected over 200 globally distributed sites.
See: http://www.esa-fire-cci.org

References:

Hantson, S., M. Padilla, D. Corti, and E. Chuvieco, 2013: Strengths and weaknesses of MODIS hotspots to characterize global fire occurrence. *Remote Sens. Environ.*, **131**, 152–159, doi:10.1016/j.rse.2012.12.004.

Hollmann, R., and Coauthors, 2013: The ESA Climate Change Initiative: Satellite data records for essential climate variables. *Bull. Amer. Meteor. Soc.*, 94, 1541–1552, doi:10.1175/BAMS-D-11-00254.1.

Mouillot, F., M. G. Schultz, C. Yue, P. Cadule, K. Tansey, P. Ciais, and E. Chuvieco, 2014: Ten years of global burned area products from spaceborne remote sensing—A review: Analysis of user needs and recommendations for future developments. *Int. J. Appl. Earth Obs. Geoinfo.*, **26**, 64–79, doi:10.1016/j.jag.2013.05.014.

Padilla, M., S. Stehman, J. Litago, and E. Chuvieco, 2014: Assessing the temporal stability of the accuracy of a time series of burned area products. *Remote Sens.*, **6**, 2050–2068, doi:10.3390/rs6032050.

Padilla, M., and Coauthors, 2015: Comparing the accuracies of remote sensing global burned area products using stratified random sampling and estimation. *Remote Sens. Environ.*, **160**, 114–121, doi:10.1016/j.rse.2015.01.005.

Padilla, M., S. V. Stehman, and E. Chuvieco, 2014: Validation of the 2008 MODIS-MCD45 global burned area product using stratified random sampling. *Remote Sens. Environ.*, **144**, 187–196. doi:10.1016/j.rse.2014.01.008.

Poulter, B., and Coauthors, 2015: Sensitivity of global terrestrial carbon cycle dynamics to variability in satellite-observed burned area. *Global Biogeochem. Cycles*, **29**, 207–222, doi:10.1002/2013GB004655.

Yue, C., and Coauthors, 2014: Modelling the role of fires in the terrestrial carbon balance by incorporating SPITFIRE into the global vegetation model ORCHIDEE – Part 1: simulating historical global burned area and fire regimes. *Geosci. Model Develop.*, **7**, 2747–2767, doi:10.5194/gmd-7-2747-2014.

5.5.15.2 GCOS/CEOS Action T36; SS: T.10

Action: Continue generation of consistent burnt area, active fire, and FRP products from low orbit satellites, including version intercomparisons to allow un-biased, long-term record development.
Who: Space agencies, in collaboration with GOFC-GOLD.
Time-Frame: Continuous.
Performance Indicator: Availability of data.
Annual Cost Implications: 1-10M US$ (Mainly by Annex-I Parties).

2015 Update

VIIRS is now entering full production phase. NASA will generate a burned are product and both NASA and NOAA are implementing a consistent MODIS-like active fire algorithm (including FRP). NASA will generate the full suite (Levels 2 and 3) while NOAA will run the compatible Level 2 real-time product. For active fires only dynamic continuity is possible due to sensor differences. The community needs to ensure continuity on the mid-morning orbit with Terra MODIS from Sentinel-3 SLSTR.

More info on VIIRS fire: http://viirsfire.geog.umd.edu/

Key publications:

Csiszar, I., W. Schroeder, L. Giglio, E. Ellicott, K. P. Vadrevu, C. O. Justice, and B. Wind, 2014: Active fires from the Suomi NPP Visible Infrared Imaging Radiometer Suite: Product status and first evaluation results. *J Geophys Res Atmos*, **119**, doi:10.1002/2013JD020453.

Schroeder, W., P. Oliva, L. Giglio, and I. A. Csiszar, 2014: The New VIIRS 375 m active fire detection data product: Algorithm description and initial assessment. *Remote Sens. Environ.*, **143**, 85–96, doi:10.1016/j.rse.2013.12.008

5.5.15.3 GCOS/CEOS Action T37; SS: T.10

Action: Develop and apply validation protocol to fire disturbance data.
Who: Space agencies and research organizations.
Time-Frame: By 2012.
Performance Indicator: Publication of accuracy statistics.
Annual Cost Implications: 1-10M US$ (Mainly by Annex-I Parties

2015 Update

The CEOS WGCV subgroup for Land Product Validation provides updated information on intercomparison and validation of fire products, including an overview of good practice and reference data sets (https://lpvs.gsfc.nasa.gov/fire_home.html). Significant process was made with respect to validation method development, burned area product intercomparison for selected years and temporal stability assessment in the framework of the ESA CCI program. Regarding reference data sets for validation, the ongoing development of higher resolution products will require a new generation (i.e., even higher resolution) of reference data. In an ongoing joint action of GCOS-TOPC experts and CEOS WGCV LPV, definitions of accuracy metrics are currently being reviewed in order to allow for an unambiguous validation of fire products.

5.5.15.4 GCOS/CEOS Action T39; SS: T10

Action: Develop set of active fire and FRP products from the global suite of operational geostationary satellites.
Who: Through operators of geostationary systems, via CGMS, GSICS, and GOFC-GOLD
Time-Frame: Continuous
Performance Indicator: Availability of products
Annual Cost Implications: 1-10M US$ (Mainly by Annex-I Parties)

2015 Update

GOES-R is planned to be launched next year and the ABI product will be a significant improvement over the current GOES. NOAA will generate and operational product. Himawari-8 was launched recently with ABI capability. MTG FCI will also have similar capability. However, the issues of inconsistency between the various missions and data access remain for at least the next several years as the new generation sensors are phased in.

5.6.1.1 GCOS/CEOS Action C8: SS: N/A

Action: Ensure continuity and over-lap of key satellite sensors; recording and archiving of all satellite metadata; maintaining appropriate data formats for all archived data; providing data service systems that ensure accessibility; undertaking reprocessing of all data relevant to climate for inclusion in integrated climate analyses and reanalyses, undertaking sustained generation of satellite-based ECV products.
Who: Space agencies and satellite data reprocessing centres.
Time-Frame: Continuing, of high priority.
Performance Indicator: Continuity and consistency of data

2015 Update

The CEOS-CGMS Working Group on Climate has been established with the over-arching goal to improve the systematic availability of Climate Data Records through the coordinated implementation, and further development of the architecture for climate monitoring from space. The objectives include:

- Provision of a structured, comprehensive and accessible view as to what Climate Data Records are currently available from satellite missions of CEOS and CGMS members or their combination;
- Creation of the conditions for delivering further Climate Data Records, including multi-mission Climate Date Records, through best use of available data to fulfil GCOS requirements (e.g. by identifying and targeting cross-calibration or re-processing gaps/shortfalls);
- Optimization of the planning of future satellite missions and constellations to expand existing and planned Climate Data Records, both in terms of coverage and record length, and to address possible gaps with respect to GCOS requirements

5.6.2.1 GCOS/CEOS Action C21; SS: N/A

Action: Implement modern distributed data services, drawing on the experiences of the WIS as it develops, with emphasis on building capacity in developing countries and countries with economies in transition, both to enable these countries to benefit from the large volumes of data available world-wide and to enable these countries to more readily provide their data to the rest of the world.
Who: Parties' national services and space agencies for implementation in general, and Parties through their support of multinational and bilateral technical cooperation programmes, and the GCOS Cooperation Mechanism.
Time-Frame: Continuing, with particular focus on the 2011-2014 time period.
Performance Indicator: Volumes of data transmitted and received by countries and agencies.
Annual Cost Implications: 30-100M US$ (90% in non-Annex-I Parties).

2015 Update

The CEOS Working Group on Information Systems and Services (WGISS - http://ceos.org/ourwork/workinggroups/wgiss/) has instituted an opensearch protocol to allow for the sharing of search results across all CEOS data collections.

Appendix 3: Acronyms

A	
ABI	Advanced Baseline Imager
ACC-VC	Atmospheric Composition Virtual Constellation (CEOS)
ACCENT	Atmospheric Composition Change the European Network
ACE	Aerosol, Clouds, and ocean Ecosystems
ACE-FTS	Atmospheric Chemistry Experiment- Fourier Transform Spectrometer
ADM-Aeolus	Atmospheric Dynamics Mission Aeolus
AERONET	Aerosol Robotic Network
AFWA	Air Force Weather Agency (United States)
AGB	Above-ground biomass
AIRS	Atmospheric Infrared Sounder
AltiKa	Ka-band altimeter
AMSR	Advanced Microwave Scanning Radiometer
AMSR2	Advanced Microwave Scanning Radiometer-2
AMSR-E	Advanced Microwave Scanning Radiometer – EOS
AMSU	Advanced Microwave Sounding Unit
ANSA	AFWA-NASA Snow Algorithm
AOPC	Atmospheric Observation Panel for Climate
ARM	Atmospheric Radiation Measurement
ASCAT	Advanced Scatterometer
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATMS	Advanced Technology Microwave Sounder
ATSR	Along Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
B	
BBR	Broadband Radiometer
BHR	BiHimispherical Reflectance
BIPM	The International Bureau of Weights and Measures
BRDF	Bidirectional Reflectance Distribution Function
BSRN	Baseline Surface Radiation Network
C	
CALM	Circumpolar Active Layer Monitoring
CCI	Climate Change Initiative
CCRS	Canadian Centre for Remote Sensing
CDR	Climate Data Record
CEOS	Committee on Earth Observation Satellites
CERES	Clouds and the Earth's Radiant Energy System

CFC	Chlorofluorocarbon
CGMS	Coordination Group for Meteorological Satellites
C-GTOS	Coastal-GTOS
ChloroGIN	Chlorophyll Global Integrated Network
CIERA	Community Initiative for Emissions Research and Applications
CIMSS	Cooperative Institute for Meteorological Satellite Studies-University of Wisconsin (United States)
CLARREO	Climate Absolute Radiance and Refractivity Observatory
CLIVAR	Climate Variability and Predictability Research Program (United States)
CliC	Climate and Crysophere
CM SAF	Satellite Application Facility on Climate Monitoring
CMA	Chinese Meteorological Administration
CNES	Centre National d'Etude Spatiales (France)
CNSA	China National Space Administration
COMS	Communication, Ocean, and Meteorological Satellite
CONAE	Comisión Nacional de Actividades Espaciales (Argentina)
COP	Conference of the Parties
COSMIC	Constellation Observing System for Meteorology, Ionosphere and Climate
CrIS	Cross-track Infrared Sounder
CSA	Canadian Space Agency
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
CTF	Carbon Task Force
CWIC	CEOS WGISS Integrated Catalog
D	
DHR	Directional-Hemispherical Reflectance
DLR	Deutsches Zentrum für Luft-und Raumfahrt (Germany)
DMSP	Defense Meteorological Satellite Program (United States)
DOAS	Differential Optical Absorption Spectroscopy
DOD	Department of Defense (United States)
DPR	Dual Precipitation Radar
E	
ECV	Essential Climate Variable
EEA	European Environment Agency
ENSO	El Niño-Southern Oscillation
ENVISAT	Environmental Satellite
EOS	Earth Observing System
ERS-2	European Remote Sensing satellite
ESA	European Space Agency
ESRIN	European Space Research Institute
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites

F	
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
FCDR	Fundamental Climate Data Record
FOV	Field of View
FRE	Fire Radiated Energy
FRP	Fire Radiative Power
FY-2C/2D	Feng Yun
G	
GACP	Global Aerosol Climatology Project
GAW	Global Atmosphere Watch
GCMP	Global Climate Monitoring Principles
GCOM	Global Change Observation Mission
GCOM-W	Global Change Observation Mission-Water
GCOS	Global Climate Observing System
GCOS IP	Global Climate Observing System Implementation Plan
GCW	Global Cryosphere Watch (WMO)
GDAP	GEWEX Data and Assessments Panel
GEIA	Global Emissions Inventory Activity
GEO	Group on Earth Observations or Geostationary orbit
GEOSS	Global Earth Observation System of Systems
GERB	Geostationary Earth Radiation Budget
GEWEX	Global Energy and Water Cycle Experiment
GFOI	Global Forest Observations Initiative
GHRSST	Group for High Resolution Sea Surface Temperature
GHG	Greenhouse Gas
GHz	Gigahertz
GLASS	GEWEX Land/Atmosphere System Study Panel
GLTC	Global Lake Temperature Collaboration
GMAO	Global Modeling and Assimilation Office
GMI	GPM Microwave Imager
GNSS	Global Navigation Satellite System
GNSS-RO	GNSS-Radio Occultation
GOES-R	Geostationary Operational Environmental Satellite-R
GOFC-GOLD	Global Observation of Forest and Land Cover Dynamics
GOMOS	Global Ozone Monitoring by Occultations of Stars
GOMS	Geostationary Orbit Meteorological Satellite
GOOS	Global Ocean Observing System
GOSAT	Greenhouse gases Observing SATellite “IBUKI”
GPM	Global Precipitation Measurement

GPP	Gross Primary Production
GPSRO	Global Positioning System Radio Occultation
GRACE	Gravity Recovery and Climate Experiment
GRUAN	GCOS Reference Upper-Air Network
GSICS	Global Space-based Inter-Calibration System
GSN	GCOS Surface Network
GTN	Global Terrestrial Networks
GTN-G	Global Terrestrial Networks-Glaciers
GTN-H	Global Terrestrial Networks-Hydrology
GTN-L	Global Terrestrial Networks-Lake Level/Area
GTN-P	Global Terrestrial Networks—Permafrost
GTN-R	Global Terrestrial Networks-Rivers
GTN-SM	Global Terrestrial Network for Soil Moisture
GTOS	Global Terrestrial Observing System
GUAN	GCOS upper air network
H	
HYDROLARE	International Data Centre on the Hydrology of Lakes and Reservoirs
I	
IACS	International Association of Cryospheric Sciences
IASI	Infrared Atmospheric Sounding Interferometer
ICESat	Ice, Cloud, and land Elevation Satellite
ICSU	International Council of Scientific Unions
IFOV	Instantaneous Field of View
IGOS	Integrated Global Observing Strategy
IGWCO	Integrated Global Water Cycle Observations
IMS	Ice Mapping System
INPE	Instituto Nacional de Pesquisas Espaciais (Brazil)
INSAT	Indian National Satellite System
IO3C	International Ozone Commission
IOC	Intergovernmental Oceanographic Commission
IOCCG	International Ocean Color Coordinating Group
IPCC	Intergovernmental Panel on Climate Change
IR	Infrared
IROWG	CGMS International Radio Occultation Working Group
IRC	International Radiation Commission
ISCCP	International Satellite Cloud Climatology Project
ISMN	International Soil Moisture Network
ISMWG	International Soil Moisture Working Group
ISRO	Indian Space Research Organisation

ISS	International Space Station
J	
JAXA	Japan Aerospace Exploration Agency
JMA	Japan Meteorological Agency
JPSS	Joint Polar Satellite System
JRC	Joint Research Centre (European Union)
K	
KNMI	Koninklijk Nederlands Meteorologisch Instituut
L	
LAI	Leaf Area Index
LEO	Low-Earth Orbit
LPV	Land Product Validation
LSI-VC	Land-Surface Imaging Virtual Constellation (CEOS)
LW	Long Wave
M	
MADRAS	Microwave Analysis and Detection of Rain and Atmospheric Structures
MAX-DOAS	Multi-Axis Differntial Optical Absorption Spectroscopy
MCR	Mission Concept Review
MERIS	Medium Resolution Imaging Spectrometer
MERRA	Modern-Era Retrospective Analysis for Research and Applications
Metop	Meteorological Operations Platform
MFG	Meteosat First Generation
MHS	Microwave Humidity Sounder
MISR	Multiangle Imaging SpectroRadiometer
MODIS	Moderate Resolution Imaging Spectroradiometer
MSG	Meteosat Second Generation
MSU	Microwave Sounding Unit
MTG	Meteosat Third Generation
MTSAT	Multi-Functional Transport Satellite
MW	Microwave
MWTS	Microwave Temperature Sounder
N	
NASA	National Aeronautics and Space Administration (United States)
NBP	Net Biome Production
NCAR	National Center for Atmospheric Research (United States)
NCEP	National Centers for Environmental Prediction (United States)
NEP	Net Ecosystem Production
NEON	National Ecological Observatory Network (United States)
NESDIS	National Environmental Satellite, Data, and Information Service (United States)

NIR	Near Infrared
NOAA	National Oceanic and Atmospheric Administration (United States)
NPL	National Physical Laboratory (United Kingdom)
NRC	National Research Council (United States)
NRL	Naval Research Laboratory (United States)
NRT	Near-Real-Time
NSIDC	National Snow and Ice Data Center (United States)
O	
OCO	Orbiting Carbon Observatory
OCR	Ocean Color Radiances
OCR-VC	Ocean Colour Radiometry Virtual Constellation
OLIVE	On Line Interactive Validation Exercise
OMPS	Ozone Mapping and Profiler Suite
OOPC	Ocean Observations Panel for Climate
ORNL DAAC	Oak Ridge National Laboratory Distributed Active Archive Center (United States)
OSIRIS	Optical Spectrograph and Infra-Red Imaging System
OST-VC	Ocean Surface Topography Virtual Constellation (CEOS)
OSVW-VC	Ocean Surface Vector Wind Virtual Constellation (CEOS)
P	
PACE	Pre-Aerosol, Clouds and ocean Ecosystem
PATMOS-x	Pathfinder Atmospheres – Extended
PC-VC	Precipitation Virtual Constellation (CEOS)
PM	Passive Microwave
POGO	Partnership for Observation of the Global Oceans
PR	Precipitation Radar
PSBE	Potential Satellite Bias Error
Q	
QA4EO	Quality Assurance for Earth Observations
R	
R2O	Research to Operations
RAMI	Radiation Transfer Model Intercomparison
RAOB	Radiosonde Observation (Upper-Air Observation)
RO	Radio Occultation
RS	Reflected Solar
RSS	Remote Sensing Systems
S	
SAC-D	Satélite de Aplicaciones Cientificas-D
SAF	Satellite Application Facility (EUMETSAT)
SAFARI	Societal Applications in Fisheries & Aquaculture using Remotely-Sensed Imagery

SAGE	Stratospheric Aerosol and Gas Experiment
SAPHIR	Sounder for Probing Vertical Profiles of Humidity
SAR	Synthetic Aperture Radar
SARAL	Satellite with Argos and Altika
SBA	Societal Benefit Area
SBSTA	UNFCCC Subsidiary Body on Scientific and Technological Advice
ScaRaB	Scanner for Radiation Budget
SCIAMACHY	SCanning Imaging Absorption SpectroMeter for Atmospheric CartograpHY
SCOPE-CM	Sustained, Co-Ordinated Processing of Environmental Satellite Data for Climate Monitoring
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SI	International Standards Units
SIMBIOS	Sensor Intercomparison for Marine Biological and Interdisciplinary Ocean Studies
SM	Soil Moisture
SMAP	Soil Moisture Active-Passive
SME	Subject Matter Expert
SMMR	Scanning Multichannel Microwave Radiometer
SMOS	Soil Moisture and Ocean Salinity
SNO	Simultaneous Nadir Overpass
SOA	State Oceanic Administration (China)
SPARC	Stratospheric Processes and their Role in Climate
SRON	Netherlands Institute for Space Research
SSM/I	Special Sensor Microwave Imager
SSMI/S	Special Sensor Microwave Imager / Sounder
SSS	Sea Surface Salinity
SST	Sea Surface Temperature
SST-VC	Sea Surface Temperature Virtual Constellation
Suomi NPP	Suomi National Polar-orbiting Partnership
SW	Short Wave
SWIR	Short Wave Infrared
T	
TanDEM-X	TerraSAR-X add-on for Digital Elevation Measurement
TBD	To be determined
TCDR	Thematic Climate Data Records
TCO	Terrestrial Carbon Observations
TIR	Thermal Infrared
TLS	Temperature Lower Stratosphere
TLT	Temperature Lower Troposphere
TMI	TRMM Microwave Imager
TMT	Temperature Middle Troposphere

TOA	Top of the Atmosphere
TOPC	Terrestrial Observations Panel for Climate
TRMM	Tropical Rainfall Measuring (also Measurement) Mission
TRUTHS	Traceable Radiometry Underpinning Terrestrial-and Helio- Studies
TTS	Temperature Troposphere / Stratosphere
U	
UAH	University of Alabama at Huntsville (United States)
UKSA	United Kingdom Space Agency
UMCP	University of Maryland, College Park (United States)
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
U.K.	United Kingdom
U.S.	United States
USGS	U.S. Geological Survey
UV	Ultraviolet
UW	University of Washington (United States)
V	
VALERI	Validation of Global Moderate-Resolution LAI Products
VC	Virtual Constellation
VIIRS	Visible/Infrared Imager/Radiometer Suite
VOSClim	Voluntary Observing Ships Climatology
W	
WACMOS	Water Cycle Observation Multi-mission Strategy
WCRP	World Climate Research Programme
WDAC	WCRP Data and Assimilation Committee
WF_ABBA	Wildfire Automated Biomass Burning Algorithm
WG	Working Group
WGCapD	Working Group on Capacity Building and Data Democracy (CEOS)
WGClimate	Working Group on Climate (CEOS)
WGCV	Working Group on Calibration and Validation (CEOS)
WGISS	Working Group on Information Systems and Services (CEOS)
WIS	WMO Information System
WMO	World Meteorological Organization
X, Y, Z	
XBT	Expendable Bathythermograph

CEOS Members and Associates

Agenzia Spaziale Italiana (ASI)

Belgian Federal Science Policy Office (BELSPO)

Canada Centre for Remote Sensing (CCRS)

Canadian Space Agency (CSA)

Centre National d'Etudes Spatiales (CNES), France

Centro para Desarrollo Tecnólogico Industrial (CDTI), Spain

China Center for Resources Satellite Data and Applications (CRESDA)

Chinese Academy of Space Technology (CAST)

Comisión Nacional de Actividades Espaciales (CONAE), Argentina

Commonwealth Scientific & Industrial Research Organisation (CSIRO), Australia

Crown Research Institute (CRI), New Zealand

Council for Scientific and Industrial Research (CSIR)/Satellite Applications Center (SAC), South Africa

Deutsches Zentrum fürLuft-und Raumfahrt (DLR), Germany

Earth Systems Science Organisation (ESSO), India

European Commission (EC)

European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)

European Space Agency (ESA)

Geo-Informatics and Space Technology Development Agency (GISTDA), Thailand

Geoscience Australia (GA)

Global Climate Observing System (GCOS)

Global Geodetic Observing System (GGOS)

Global Ocean Observing System (GOOS)

Global Terrestrial Observing System (GTOS)

Indian Space Research Organisation (ISRO)

Instituto Nacional de Pesquisas Espaciais (INPE), Brazil

Intergovernmental Oceanographic Commission (IOC)

International Council for Science (ICSU)

International Geosphere-Biosphere Programme (IGBP)

International Ocean Colour Coordinating Group (IOCCG)

International Society of Photogrammetry and Remote Sensing (ISPRS)

MEXT (Ministry of Education, Culture, Sports, Science, and Technology/Japan Aerospace Exploration Agency (JAXA)

Korea Aerospace Research Institute (KARI)

National Aeronautics and Space Administration (NASA), USA

National Oceanic and Atmospheric Administration (NOAA), USA

National Remote Sensing Center of China (NRSCC)

National Satellite Meteorological Center/Chinese Meteorological Association (NSMC/CMA)

National Space Agency of Ukraine (NSAU)

National Space Research Agency of Nigeria (NASRDA)

Netherlands Space Office (NSO)

Norwegian Space Center (NSC)

Russian Federal Space Agency (ROSKOSMOS)

Russian Federal Service for Hydrometeorology and Environmental Monitoring (ROSHYDROMET)

Scientific and Technological Research Council of Turkey (TÜBITAK)

South African National Space Agency (SANSA)

Swedish National Space Board (SNSB)

United Kingdom Space Agency (UKSA)

United Nations Economic and Social Commission for Asia and the Pacific (ESCAP)

United Nations Educational, Scientific and Cultural Organization (UNESCO)

United Nations Environment Programme (UNEP)

United Nations Food and Agriculture Organization (FAO)

United Nations Office for Outer Space Affairs (UNOOSA)

United States Geological Survey (USGS)

Vietnam Academy of Science and Technology (VAST)

World Climate Research Programme (WCRP)

World Meteorological Organization (WMO)

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China National Space Administration

Environment Canada

The European Space Agency

EUMETSAT

Global Climate Observing System (GCOS)

India Meteorological Department

Indian Space Research Organisation

Intergovernmental Oceanographic Commission / UNESCO

Japan Aerospace Exploration Agency

Japan Meteorological Agency

Korea Aerospace Research Institute

Korea Meteorological Administration

Korea Ocean Research & Development Institute

National Aeronautics and Space Administration

National Oceanic and Atmospheric administration

Russian Federal Space Agency

Russian Federal Service for Hydrometeorology and Environmental Monitoring

State Oceanic Administration (China)

World Meteorological Organization

CGMS