

# CEOS Precipitation Constellation

Steven P. Neeck<sup>a</sup>, Riko Oki<sup>b</sup>

<sup>a</sup>NASA Headquarters, Washington, DC 20546, USA

<sup>b</sup>JAXA Earth Observation Research Center, Tsukuba, Ibaraki 305-8585, Japan

## ABSTRACT

The outcomes of the 19th Committee on Earth Observing Satellites (CEOS) Plenary held in London in November 2005<sup>1,2</sup>, recognized that the CEOS Implementation Plan for Space-Based Observations for Global Earth Observation System of Systems (GEOSS) should:

- identify the supply of space-based observations required to satisfy the requirements expressed by the 10-year implementation plan for GEOSS<sup>3</sup>; and
- propose an innovative process whereby the many disparate types of Earth observing programs funded by CEOS Member agencies might contribute to the supply of the required observations.

The CEOS Task Force charged with drafting the CEOS Implementation Plan for Space-Based Observations for GEOSS focused its early efforts on the creation of a ‘new planning process’ which would satisfy the various criteria demanded by member space agencies, and which would hopefully encourage a new phase of specificity and focus in the multi-lateral co-operation efforts undertaken by space agencies under the CEOS umbrella – resulting in improved engagement of all CEOS Members and real implementation results. The CEOS Constellations is the title given to this new process, and four pilot studies have been initiated in order to pioneer and test the concept. The Japan Aerospace Exploration Agency (JAXA) and the National Aeronautics and Space Administration (NASA) were selected as the lead agencies for the study of the development of a CEOS Precipitation Constellation with the support of other CEOS space agency and user community participants. The goals, approach, and anticipated outcomes for the study will be discussed.

## 1. INTRODUCTION

Precipitation is a key element of the global water cycle and the primary source of freshwater. Accurate and timely knowledge of global precipitation is needed for improving predictive skills of high-impact weather events such as hurricanes, floods, droughts, and landslides, as well as the management of freshwater resources. A comprehensive description of the space-time variability of global precipitation is also requisite for understanding the complex interactions of the weather, climate, and ecological systems. Global long-term monitoring of precipitation is also necessary for detecting regional rainfall trends in the context of climate change and for validating model predictions. However, observations of global precipitation pose a special challenge in that precipitation phenomena involve small-scale and often stochastic processes that vary rapidly in space and time. With limited rainfall measurement networks over land and the impracticality of making extensive rainfall measurements over oceans, comprehensive observations of global precipitation can only be achieved from the vantage point of space. This can be accomplished in the near term with a coordinated constellation of low-Earth-orbiting satellites, while moving towards a system of geostationary satellites with advanced designs of microwave sensors.

The CEOS Precipitation Constellation (PC) is unique in having (1) an existing constellation of precipitation sensors using the NASA/JAXA Tropical Rainfall Measuring Mission (TRMM) satellite<sup>4,5</sup> as a reference for providing multiple merged multi-satellite global precipitation products for research and applications, and (2) an international constellation satellite mission, the Global Precipitation Measurement (GPM) mission<sup>6,7</sup> planned for deployment early in the next decade.

GPM is designed from its inception as an international satellite mission to unify and advance global precipitation measurements to provide the world community next-generation global precipitation products

for research and applications. The GPM concept is based on using combined radar/radiometer measurements on a Core Spacecraft as the reference standard to inter-calibrate observations from a diverse set of partner-provided research and operational microwave instruments within a consistent framework.

The CEOS PC study phase covers 2007. In developing a satellite constellation to provide comprehensive observations of global precipitation, the CEOS PC adopts the GPM concept as its scientific cornerstone, and the implementation of CEOS PC is to leverage off the GPM mission's research and application activities throughout GPM's preparatory phase (2007-2013) and its planned mission phase from 2013 to 2018 (at the minimum). During GPM's mission life, the GPM constellation of satellites delivering global precipitation products is envisioned to be a mature realization of the CEOS PC. The lessons learned from GPM will serve to guide the evolution of CEOS PC activities in the post-GPM phase.

The CEOS PC will contribute to the Fundamental Climate Data Records and sustained information service(s) for societal benefit – driven by the user requirements as expressed in the GEOSS Implementation Plan, the GCOS Implementation Plan<sup>8</sup>, and IGOS Theme Reports<sup>9</sup>.

The CEOS PC directly supports four of the nine Group on Earth Observation (GEO)<sup>10</sup> Societal Benefit Areas SBAs: Water, Climate, Weather, Disasters.

Consistent with the guidance provided by the CEOS Constellations Process Paper and to aid in the accomplishment of PC goals and objectives, the PC study team will prepare an Implementation Plan and a Work Plan<sup>11</sup> to guide its activities directed toward achieving the Constellation goals. The Work Plan will identify assessments and projects to be accomplished. This 2007 Work Plan is the first Work Plan prepared by the CEOS PC team.

## **2. PC PARTICIPATION**

Participation in the CEOS PC is open to all Space Agencies with existing or planned space-borne assets capable of monitoring precipitation. Currently NASA, JAXA, the National Oceanic and Atmospheric Administration (NOAA), EUMETSAT, Naval Research Laboratory (NRL), the Indian Space Research Organisation (ISRO), Centre National d'Etudes Spatiales (CNES), Agência Espacial Brasileira (AEB)/Instituto Nacional de Pesquisas Espaciais (INPE) are actively discussing space assets for the GPM constellation. In addition, agencies providing substantial ground validation assets that can be used to evaluate the space-borne constellation will also be invited to participate in the planning of the PC.

Per the guidance provided in the CEOS Constellations Process paper, the Precipitation Constellation will engage key participants from the major stakeholder user communities and will make best use of existing and potential requirements definitions – including the extensive body of work available within the Integrated Global Observing Strategy (IGOS) Global Water Cycle Observations Theme report and the recent Global Climate Observing System (GCOS) Satellite Supplement.

## **3. SCOPE AND DEFINITION**

A precipitation constellation already exists based on the presence of TRMM and the current generation of radiometric sensors including the Special Sensor Microwave/Imager (SSM/I) and Special Sensor Microwave Imager/Sounder (SSMIS), Advanced Microwave Scanning Radiometer-EOS (AMSR-E), and others. The CEOS implementation phase will begin by quantitatively assessing the existing multi-satellite precipitation products using different merging techniques, followed by the development of common reference standards for inter-calibrating both radiometric measurements and precipitation products provided by the constellation sensors. For CEOS PC implementation, GPM is to continue building partnerships to include all key precipitation radars and radiometers as a part of the GPM constellation to ensure the CEOS PC has the necessary infrastructure support for international cooperation on algorithm development, ground validation, and data exchange standards. The work objectives and plans are directed towards the goal of creating processes to achieve sustainability of the PC.

For the 2007 work plan the focus is on defining the nature and processes of the PC in the short term. Longer term issues will be deferred. In particular, the focus will be on:

- Defining the nature of the membership within the PC. The goals and objectives of the PC must be defined. When is a satellite instrument, scientific algorithm development, validation procedure or site considered part of the PC family?
- Defining policies, standards and protocols for data processing, archiving, exchange and use.
- Defining the nature of the processes and phases for on-going implementation of the PC.
- Define the scientific collaboration processes – workshops, web sites, data protocols, etc.
- Outreach to applications and users for end-user linkages and capacity building.

#### **4. GOALS OF THE PRECIPITATION CONSTELLATION**

The overarching purpose of the CEOS PC study is to establish an international framework to guide, facilitate, and coordinate the continued advancements of multi-satellite global precipitation missions. This purpose is fulfilled through two broad goals.

1. To provide a framework for implementation and monitoring of GEO task AR-06-10 Advocate and facilitate the timely implementation of the Global Precipitation Measurement (GPM) mission and encourage more nations to contribute to the GPM constellation NASA and JAXA are recognized as the lead agencies in this endeavor given their planning of the US-Japan GPM satellite program – but other space agencies have expressed interest and plans for the provision of precipitation observations – including Europe, China, India and others. The constellations concept is extremely well suited to the task of consolidating the agreement between US and Japan for GPM whilst establishing optimal conditions for other nations to contribute to satisfying the end goal of key application needs. The PC will build upon the spatial and temporal coverage provided by the US-Japan GPM mission, currently scheduled to begin operations in 2013.
2. To sustain and enhance an accurate and timely global precipitation data record including a Fundamental Climate Data Record essential for understanding the integrated weather/climate/ecological system, managing freshwater resources, and monitoring and predicting high-impact natural hazard events. This data record should be fit for the purpose specified by GCOS for the monitoring of Precipitation as an essential climate variable (ECV) (as defined in the recent GCOS document ‘Systematic Observation Requirements for Satellite-based Products for Climate’).

#### **5. IMPLEMENTATION**

The implementation of CEOS PC will proceed in four phases (see Figure 1). The first phase is the “study phase” which covers 2007. In the study phase, the CEOS PC team will study key items which should be achieved to formulate the CEOS PC, and produce the initial Implementation Plan. The CEOS PC study should identify the key points of agreement for space agency co-operation in order to meet the needs of both the data producer and user communities. During this phase, the CEOS PC team will study the existing multi-sensor activities undertaken by PC team members. These include the following standard and prototype products:

- NASA TRMM 3B42 standard product
- JAXA GSMaP prototype product
- NOAA CMORPH/QMORPH products
- NRL products

- EUMETSAT MPE product (To Be Confirmed)

The second phase is “GPM preparatory phase” during 2008-2012, before the launch of the GPM Core satellite. During this phase, the scientific and user communities should focus on (i) comparison of different methods of inter-calibration for generating uniform precipitation estimates from diverse types of precipitation sensors, (ii) evaluation of different multi-sensor precipitation products, (iii) the prototyping of uses of merged data products from multiple sensors as well as evaluation of tools to support such use, and (iv) establishing the standard merged precipitation products desired.

The third phase is “GPM phase” during 2013-2018, after the launch of the GPM Core satellite. In the GPM phase, launch and operation of GPM, the first constellation focused mission that will improve precipitation estimates through extensive inter-calibration and the use of a reference standard, will be achieved. Currently, the GPM spacecrafts are designed to carry consumables sized for a minimum of 5 years. The “GPM phase” may extend beyond 2018 pending the outcome of periodic science and satellite performance evaluations.

The fourth phase, post-GPM phase, will be beyond timeframe of GEOSS 10-Year Implementation Plan. Therefore, activities during this phase will not be specified clearly in an early stage. The lessons learned from GPM, however, will serve to guide the planning and further evolution of CEOS PC activities in the post-GPM phase.

year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
phase	Study phase	GPM preparatory phase					GPM phase					Post-GPM phase	
							GPM						

Figure 1. CEOS PC Phases

## 6. 2007 OBJECTIVES, ACTIVITIES, AND DELIVERABLES

Below are the objectives, activities and deliverables of 2007.

Implementation objectives of the study phase (2007) will focus on the organization of the PC study team, the establishment of the framework for PC activities, and the initial interactions of the PC leads and contributing members for the PC. These PC activities will be harmonized with past and current efforts made by the GPM mission. In addition, the PC study team will improve the dissemination and usage of precipitation data from constellation satellites available in the GPM preparatory phase.

Activities:

1. Establish the framework in which existing and planned missions could work synergistically to meet international user community requirements and GEOSS societal benefit areas.
  - Establish the CEOS PC team, led by the CEOS PC co-chairs.
  - Hold meetings of the PC team, and workshops of the PC partners.
  - Develop the initial Implementation Plan, including study report of 2007, activities and its schedule for GPM preparatory and GPM phases.
  - Clarify function, competence, role, membership and principles for participation in order to develop the CEOS PC framework.
    - Overall coordination framework to have functions of interface with users and other external bodies, such as International Precipitation Working Group (IPWG), Co-ordination Group for Meteorological Satellites (CGMS), World Meteorological Organization (WMO), GEO, etc.

- Seek linkage between the CEOS PC and existing and potential user communities to improve their applications.
2. Coordinate inputs based on emerging societal benefit areas and established user requirements from both the research and operational communities with existing GPM plans, including both science and operational views.
- Clarify and categorize existing requirements.
  - Clarify general requirements for the CEOS PC, to be included in the PC IP.
    - Establish how existing and planned missions could work synergistically to meet international user community requirements and GEOSS societal benefit areas.
    - Develop a list of existing and upcoming satellite systems and specifications of instruments in the GPM preparatory and GPM phases.
    - Encourage and support science for the merging of data from multiple radiometers.

Define enhancements in the areas of cal/val, quality control, and data accessibility and interoperability.

- Clarify the advantages and improvements of the Precipitation Constellation in the area of cal/val, quality control to be incorporated to the Implementation Plan.
- Develop and evaluate prototype reference standard for intercalibrating existing microwave sensors in coordination with the GSICS research working group under WWW/GOS.

Develop a baseline framework for data exchange and cross-evaluation

- Study issues on general principles of data policy to enable the 'required' data exchange
- Support the wide dissemination of data of merged products as well as data from sensors in the current constellation

Define the 'key points of agreement' in technical areas regarding each stage of the Constellation that would be required to realize the common goals and the existence of a working CEOS PC.

- List technical issues to be included in the Implementation Plan for:
  - space segment commonalities including sensor characteristics and satellite system characteristics (e.g., data transmission, orbit, etc.)
  - the framework and systems for data and product access and exchange
  - arrangements for interoperability in data, products and services
  - inter-operability in data processing, archiving and dissemination

## **7. STUDY OUTCOMES**

While outcomes for 2007 will include reports of joint activities, CEOS PC team members have agreed to provide the following from individual member contributors as contributions to the PC. The CEOS PC team will then analyze these activities during the GPM preparatory phase, taking into account results from 2007 study, to ascertain what aspects should be carried forward into PC deliverables in future years.

In the Study Phase (2007) these will include:

- Report of 2007 activities
- Establishment of the PC team led by the PC co-chairs
- Meetings among the PC team members
- Workshops among the PC partners
- Initial Implementation Plan for the PC, including study report, general requirements, etc.
- In the area of Hardware; Satellite, sensor, data distribution systems, etc.
  - 10 year TRMM operations and approval of TRMM operations

- Continued development of GPM
- Definition of the Series Standards
- In the area of Software; Algorithm development/improvement, data-processing, products
  - Support science related to constellation including: algorithm development and improvement for multi-satellite inter-calibration, multi-satellite precipitation products and application of precipitation products to hydrology, etc.
  - Creation of intercalibrated brightness temperature dataset to enable a prototype reference standard for intercalibrating existing microwave sensors
  - Completion of 10-years of TRMM standard products including multi-satellite precipitation analysis (3B42)
  - Precipitation data set for climate study
  - Global precipitation map (GSMAP)
  - Tropical cyclone database
  - Precipitation Processing System
- In the area of Applications
  - Prototype data systems for application
  - IFNet/Global Flood Alert System (GFAS) Prototype
  - NASA hydrological applications (Real time flood potential, landslide hazards)
  - Typhoon information service
  - WTF-CEOP distributed data system for integrated CEOP data sets
  - Capacity building activities
  - Asian Water Cycle Initiative

Additional outcomes have been proposed by the PC participants and are being incorporated in the 2007 PC Work Plan.

In the longer term, i.e. during the GPM preparatory phase (2008-2012), the GPM phase (2013-2017), and the Post-GPM phase (after 2017), the outcome will be the subject of the PC Implementation Plan development.

## **8. JUNE 14-15, 2007 WORKSHOP**

To initiate PC activities, NASA and JAXA co-hosted the 1st CEOS Precipitation Constellation Workshop in Washington DC U.S.A. on June 14-15, 2007. 31 participants from 15 nations/organizations were represented. The workshop objectives were:

1. Agreement on the Precipitation Constellation concept and its objectives.
2. Agreement of space agencies, other organizations, and users to participate.
3. Review of the key points of the CEOS Precipitation Constellation Work Plan proposed by NASA and JAXA.
4. Jointly draft the final Work Plan based on the consensus of the participating CEOS Precipitation Constellation Members.
5. Identify Precipitation Constellation activities and demonstrations in time for GEO Summit - Nov 2007.

All workshop objectives were met and additional workshops to further broaden international participation, refine goals, and accomplish PC activities are planned.

## **9. LINKAGES TO GEOSS SPACE SEGMENT AND CEOS IP**

The CEOS PC has linkages to the GEOSS space segment and CEOS IP in numerous areas. These include:

1. GEOSS 10 Year Implementation Plan Reference Document, GEO 1000R, February 2005:
  - a. Water 2 Year Target:

- i. Facilitate, with space agencies and research communities, more accurate, frequent (3-hourly), global, high spatial resolution, and microphysically detailed measurements of precipitation through a global constellation of satellites carrying passive microwave radiometers in complementary orbits.
  - b. Water 6 Year Target:
    - i. Facilitate, with space agencies and research communities, the development of effective sensors and missions for Global Precipitation Measurement (GPM), surface and subsurface water stores – including snow water equivalence, water stored in natural and man-made reservoirs, and groundwater.
  - c. Water 10 Year Target:
    - i. Facilitate improved simulation and prediction capabilities for precipitation, water cycling and water cycle acceleration in weather and climate models.
  - d. Weather 2 Year Target:
    - i. Facilitate investment in the critical data gaps (atmospheric wind and humidity profiles, ocean evaporation and precipitation, soil moisture, precipitation) and improve predictive models to augment the quality of forecasts of severe events and general weather conditions.
  - e. Climate 10 Year Target:
    - i. Support implementation of actions called for in the GCOS Implementation Plan and the relevant IGOS-P Theme Reports.
- 2. GEO 2007–2009 Work Plan<sup>13</sup> tasks:
  - a. DA-07-03 Virtual Constellations
  - b. AR-06-10 The CEOS Constellation for Precipitation
- 3. CEOS IP:
  - a. 1st Priority Climate Actions
    - i. Climate-A-4
  - b. GEOSS Long Term targets
    - 2.6 Water GEO Target Reference 44 and 142
    - 2.7 Weather GEO Target Reference 53
- 4. CEOS IP Targets V 1.0:
  - a. CL-2006-01 Implement GCOS-IP
  - b. CL-2006-02 Support research for development of observations for key ECVs
  - c. WA-2007-01 Plan for 3 hourly global precipitation products
  - d. WA-2007-03 Implementation plan for data integration system
  - e. WA-2007-04 Integrated precipitation and soil moisture products
  - f. WE-2007-01 Invest in critical data gaps (precipitation)

## **10. CONCLUSION**

The PC is one of four pilot projects initiated by CEOS to bring about technical/scientific cooperation and collaboration among space agencies that meet GEO objectives and also support national priorities. The effort, led by JAXA and NASA, has been initiated and actively involves Space Agencies, other interested organizations, and user community representatives<sup>14</sup>.

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