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## **Status of GPM and CEOS Precipitation Constellation**

The current status of the Global Precipitation Measurement (GPM), Japan-US joint mission, and JAXA's Dual-frequency Precipitation Radar (DPR) onboard the GPM core satellite, are reported. Activity of CEOS Precipitation Constellation, one of CEOS virtual constellations, is also reported.

## 1 Introduction

One of the major concerns of the present day is the global change of our environment. To assess the effect of changes in each environmental factor on the global environment, we need to know its present status, relationship to other factors, and the mechanism how it affects the environment. Among many environmental factors, precipitation is one of the most important components. In fact, it affects everyone's life and work. Too much precipitation causes floods, and too less of it causes droughts. Agricultural production depends on precipitation. It is one of the three foremost weather prediction variables along with temperature and wind. It is a true global variable that determines the general circulation through latent heating and reflects climate changes. It is a key component of air-sea interaction and eco-hydrometeorological modelling.

Even though precipitation is such an important component of our environment, it is one of the least known physics components of cloud-weather-climate prediction models. Because of its large variability in space and time, its distribution over the globe is not very accurately known. Knowledge of the spatial and temporal distribution of global precipitation is a key to improve our understanding of weather and climate systems.

The Global Precipitation Measurement (GPM) is a follow-on and expand mission of the Tropical Rainfall Measuring Mission (TRMM). TRMM is a joint Japan-US mission, and was launched in the end of November 1997 by H-II rocket. TRMM targeted to measuring tropical/subtropical rainfall and their diurnal variations, and covers latitude from 35S to 35N. TRMM has three precipitation sensors, Precipitation Radar (PR), the world first space-borne precipitation radar, and TRMM Microwave Imager (TMI) and Visible Infrared Scanner (VIRS), which enable to observe rainfall structures by multiple sensors, simultaneously. TRMM is still in operation and its data was accumulated over 10-years.

GPM is a satellite program to measure the global distribution of precipitation accurately in a sufficient frequency so that the information provided by this program can drastically improve weather predictions, climate modelling, and understanding of water cycles. Its feasibility has been studied at Goddard Space Flight Center of National Aeronautics and Space Administration (NASA) and JAXA. The accurate measurement of precipitation will be achieved by the Dual-frequency Precipitation Radar (DPR) installed on the GPM core satellite. DPR on the GPM core satellite is being developed by JAXA and National Institute of Information and Communications Technology (NICT).

## 2 GPM

### 2.1 Mission Objectives

Prospects for the GPM sciences consist of three research fields; climate, weather, and water cycle.

In climate research, the accumulations of accurate rainfall amount provided by GPM will be used for testing and improving climate models. Current global climate models do not predict the changes of precipitation associated with the global warming well. In fact, GPM data may be useful in detecting a long-term change of precipitation distribution, especially when they are combined with TRMM and other historical surface and satellite data.

In weather forecast, assimilation of precipitation data in numerical weather prediction models will improve precipitation forecast substantially. Such an improvement has been shown in case studies with the TRMM data. GPM's three-hourly precipitation data will enable us to realize assimilation for improved forecast in operational use. GPM data is expected to contribute to accurate global rainfall and moisture analysis, and frequent and accurate observation/analysis of severe weather systems. Through such analyses, improvement of numerical weather prediction models is expected, which results in better long-term forecasts at all scales.

In global water cycle studies, improvement of precipitation measurements both in time- and space-coverage provided by GPM will significantly reduce the uncertainties in the earth's water cycle and will result in the improvement of hydrological models. GPM data may make a great step forward to solve the central issues to quantify variability of water cycle and understand mechanisms underlying the variability, and distinguish human induced and natural variability in the water cycle. Flood predictions and water management can benefit from the improved weather forecast as well.

In addition to those scientific and research fields, GPM may impact many other surrounding research areas. They include studies in cloud system and radiation, ocean-land atmosphere interactions, freshwater forcing on ocean processes, ocean salinity modelling, development of hydrometeorology and carbon assimilation models, soil moisture and its impact on flood/drought prediction, and water vapor transport, to mention a few.

## 2.2 System Overview

The GPM mission (Figure 1) is consist of two categories of satellites. One of is the TRMM-type core satellite (Figure 2) jointly developed by U.S. and Japan that will carry an active precipitation radar and a passive microwave radiometer as a calibrator to other satellites. The other is a constellation of several satellites developed by each international partner (space agency) that will carry passive microwave radiometers and/or microwave sounders. The core satellite will make detailed and accurate estimates of precipitation structure and microphysical properties, while the constellation of satellites will provide required temporal sampling of highly variable precipitation systems.

GPM will extend TRMM's observations of precipitation to higher latitudes with non-sun-synchronous orbit of 65° inclination angle (Table 1), thus yielding more complete and accurate representation of global precipitation distribution. The TRMM PR has been providing accurate rain data and detailed three-dimensional structure inside rain systems over both ocean and land. Such unique data that can be obtained only by radar will be expanded to the whole globe. Furthermore, three-hourly global precipitation maps are expected to be used for operational applications such as numerical weather forecasts and water resources management. The transient nature of precipitation makes the detection of subtle changes difficult. Precipitation information over approximately three-hourly time scales is needed to improve numerical prediction, data assimilation and flood forecast models. To observe global precipitation within every three hours, several microwave radiometers in polar orbit are needed. These will be successors of the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) onboard NASA's Aqua satellite, and the Special Sensor Microwave/Imager (SSM/I) onboard the Defense Meteorological Satellite Program (DMSP) satellites.

JAXA is planning a future satellite mission, which could be one of GPM constellation satellites. The Global Change Observing Mission (GCOM) is a follow-on mission of the Advance Earth Observing Satellite-II (ADEOS-II), to establish and demonstrate global and long-term earth observation system for understanding climate variability and water-energy cycle. GCOM mission consists of two satellites series (GCOM-W and GCOM-C) of three generations with one-year overlap to achieve homogeneous and steady observation more than 13 years. GCOM-W (Water) will focus on variability of global water-energy cycle and extend successful AMSR/AMSR-E observation to contribute to world water relevant issues. The first generation of GCOM-W (called GCOM-W1), which carries the Advanced Microwave Scanning Radiometer 2 (AMSR2), the successor of AMSR-E, is scheduled to be launched in January 2012.

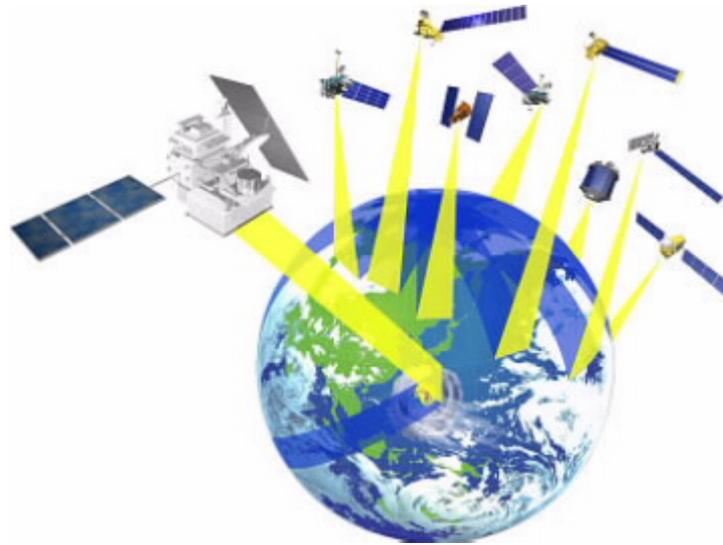


Figure 1: Overview of GPM mission concept

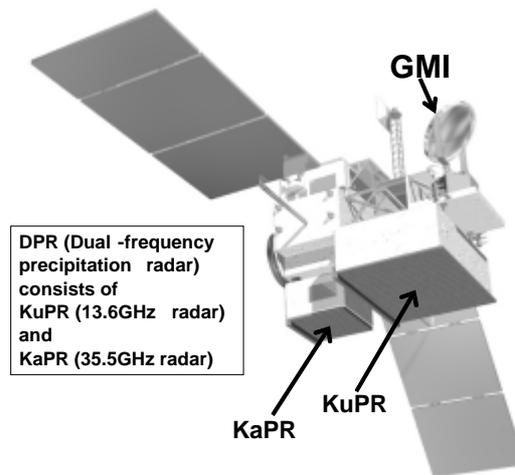


Figure 2: Overview of GPM core satellite

Table 1: Major Characteristics of GPM core satellite

Instrument	Dual-frequency Precipitation Radar (DPR) GPM Microwave Imager (GMI)
Orbit	Non-sun-synchronous orbit Altitude: 407km Inclination: 65 degrees
Launch	July 2013
Status	NASA Mission PDR scheduled for November 2008 Critical Design of JAXA DPR started in 2008

The GPM core satellite will play an essential role in the whole concept of GPM. Based on detailed information that will be obtained by the precipitation radar and the multi-frequency microwave radiometer on the core satellite, data from microwave radiometers on other satellites will be calibrated and validated accurately. The GPM core satellite carries two core sensors; GPM

Microwave Imager (GMI) will be developed by NASA, and Dual-Frequency Precipitation Radar (DPR) by JAXA and NICT. The precipitation radar is the key sensor of the whole GPM program. In addition to the Ku-band (13.6GHz) radar that is nearly identical to the TRMM Precipitation Radar (PR), a Ka-band (35.5GHz) channel will be added to DPR on the GPM core satellite. By utilizing these two frequencies, radar measurement of weak rain and snow in mid- and high-latitudes will be realized. Using differential attenuation information between the two frequencies, classification of drop size distribution (DSD) is expected. The DSD information provided by the DPR will be used to reduce the error in rain estimates from multi-channel microwave radiometers. Major characteristics of DPR are shown in Table 2. KuPR and KaPR engineering test model fabrication was completed, and testing on-going for design verification purpose (Fig.4), and KuPR and KaPR flight parts manufacturing already has been started.

**Table 2: Major characteristics of DPR**

Name	KuPR	KaPR
radar type	active phased array radar	
antenna	slotted waveguide antenna	
frequency	Ku-band 13.6 GHz	Ka-band 35.55 GHz
peak transmit power	> 1000 W	> 140 W
swath	245 km	125 km
horizontal resolution	5 km	
range resolution	250 m	250m/500m
observation altitude	surface ~ 19 km	
observation rainrate	0.5 mm/h ~	0.2 mm/h ~
size	2.4 m x 2.4 m x 0.6 m	1.44 m x 1.07 m x 0.7 m
	< 470 kg	< 336 kg

### 2.3 Data Products

There are three kinds of products that are Standard product, Research product and Near-real time product. Research products are the ones in research phases; however, those have possibilities to be Standard products. Near-real time products will be generated using estimated orbital information for prompt data release and distributed to users who need GPM data as soon as possible for their operational purposes.

Current plan of JAXA GPM products is shown in Table 3. Other than these products listed up in Table 3, some of the GPM standard products processed at NASA will be distributed from JAXA. GPM standard products will be authorized between the U.S. and Japan GPM joint science team.

JAXA is responsible for the GPM/DPR algorithm development for engineering values (Level 1) and physical products (e.g. precipitation estimation) (Level 2 and 3) and the quality control of the products as the sensor provider. Furthermore, JAXA is planning to generate rain map data from multiple satellite information, considering the data needs in some operational areas such as weather forecasts and flood warning, mapped precipitation data with high temporal resolution. DPR/GMI combined algorithms will be based on DPR maximizing the use of DPR information. Currently it is considered as a research product having possibility to be the future standard product.

**Table 3: Draft plan of JAXA GPM products. The values of swath and resolutions are the ones when the altitude of the satellite is 407km. Other than these products listed up in this table, some of the GPM standard products processed at NASA will be distributed from JAXA. GPM standard products will be authorized between the U.S. and Japan GPM joint science team.**

JAXA Standard Products							
Product Level	Algorithm	Major Parameters	Scene Unit	Swath	Resolution		Product Size
					Horizontal	Vertical	
1	KuPR Algorithm	Received Power, Radar Reflectivity	1 orbit	245km	5km	125m	370MB
	KaPR Algorithm	Received Power, Radar Reflectivity	1 orbit	125km	5km	125m/250m	250MB
2	KuPR Algorithm	Surface Cross Section, Precipitation Type, Bright Band Height, Corrected Z-factor, Precipitation Rate Profile	1 orbit	245km	7km	125m	440MB
	KaPR Algorithm	Surface Cross Section, Precipitation Type, Bright Band Height, Corrected Z-factor, Precipitation Rate Profile	1 orbit	125km	5km	125m	360MB
	Dual-frequency Algorithm	Precipitation Rate, Precipitation Drop-size Distribution (N0,D0), Rain or Snow, Attenuation Profile	1 orbit	245km	5km	250m	400MB
3	Dual-frequency Algorithm	Precipitation Mean, Total Counts, Precipitation Pixels, Mean of Bright Band Height, etc.	monthly	(global)	0.5° x 0.5°	250m	320MB
	Global Precipitation Map Algorithm	Precipitation Mean, Total Counts, Precipitation Pixels	3-hour monthly	(global)	TBD	—	TBD
JAXA Near Real-time Products							
Product Level	Algorithm	Major Parameters	Scene Unit	Swath	Resolution		Product Size
					Horizontal	Vertical	
1R	Sensor dependent	Microwave Radiometer Brightness Temperature	variable	Sensor dependent	Sensor dependent	—	Sensor dependent
2R	Dual-frequency Algorithm	Precipitation Rate, Precipitation Drop-size Distribution (N0,D0), Rain or Snow, Attenuation Profile	variable	245km	5km	250m	400MB
3R	Global Precipitation Map Algorithm	Precipitation Mean, Total Counts, Precipitation Pixels	TBD	(global)	TBD	—	TBD
JAXA Research Products							
Product Level	Algorithm	Major Parameters	Scene Unit	Swath	Resolution		Product Size
					Horizontal	Vertical	
2	DPR/GMI Combined Algorithm	Precipitation Rate profile	1 orbit	245km	5km	250m	TBD
		Surface Precipitation	1 orbit	800km	7km	—	TBD
3	DPR/GMI Combined Algorithm	Surface Precipitation Mean, Total Counts, Precipitation Pixels	monthly	(global)	0.5° x 0.5°	—	3MB

### 3 CEOS Precipitation Constellation Concept

In 2006, the Committee on Earth Observation Satellites (CEOS), which is principal coordination mechanisms for international/national Earth observation satellite programs and GEOSS space segment, approved concept of “CEOS Constellation,” and proposed it as a contribution of CEOS



to the Global Earth Observation System of Systems (GEOSS). Its concept is to construct "virtual" constellation of Earth observation satellites planned/developed by national space agencies by standardizing of data format, sensors, and satellite and ground systems.

CEOS Precipitation Constellation (PC) is proposed as one of first four virtual constellations, and JAXA and NASA is co-leading CEOS PC activities with other participating agencies. The goal of the CEOS PC is to establish an international framework to guide, facilitate, and coordinate the continued advancements of multi-satellite global precipitation products. As compared to other virtual constellations, the CEOS PC is unique in having an existing constellation of precipitation sensors using TRMM as a reference for providing multiple merged multi-satellite global precipitation products for research and applications, and an existing international constellation satellite mission, GPM Mission.

CEOS PC holds annual meeting (International workshop) to exchange information of the individual satellite projects and specifications of instruments, and to establish annual Work Plan to implement the broad goals and specific phase objectives outlined in the PC Implementation Plan. CEOS PC 2008 Work Plan and 10-year Implementation Plan were released in Aug 2008.