APPENDIX 1
OVERVIEW OF THE GLOBAL CHANGE OBSERVATION MISSION (GCOM)

1. Introduction

Comprehensive observation, understanding, assessment, and prediction of global climate change are common and important issues for all mankind. This is also identified as one of the important socio-economic benefits by the 10-year implementation plan for Earth Observation that was adopted by the Third Earth Observation Summit to achieve the Global Earth Observation System of Systems (GEOSS). International efforts to comprehensively monitor the Earth by integrating various satellites, in-situ measurements, and models are gaining importance. As a contribution to this activity, the Japan Aerospace Exploration Agency (JAXA) plans to develop the Global Change Observation Mission (GCOM). GCOM will take over the mission of the Advanced Earth Observing Satellite-II (ADEOS-II) and develop into long-term monitoring of the Earth.

As mentioned in the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC), warming of the climate system is unequivocal as is now evident from observations of increases in global average air and ocean temperatures and widespread melting of snow and ice. However, climate change signals are generally small and modulated by natural variability, and are not necessarily uniform over the Earth. Therefore, the observing system of the climate variability should be stable, and should cover a long term over the entire Earth.

To satisfy these needs, GCOM consists of two medium-size, polar-orbiting satellite series and multiple generations (e.g., three generations) with one-year overlaps between consecutive generations for inter-calibration. The two satellite series are GCOM-W (Water) and GCOM-C (Climate). Two instruments were selected to cover a wide range of geophysical parameters: the Advanced Microwave Scanning Radiometer-2 (AMSR2) on GCOM-W and the Second-generation Global Imager (SGLI) on GCOM-C. The AMSR2 instrument will perform observations related to the global water and energy cycle, while the SGLI will conduct surface and atmospheric measurements related to the carbon cycle and radiation budget. This chapter presents an overview of the mission objectives, observing systems, and data products of GCOM.

2. Mission Objectives

The major objectives of GCOM can be summarized as follows.

- Establish and demonstrate a global, long-term Earth-observing system for understanding climate variability and the water-energy cycle.
- Enhance the capability of climate prediction and provide information to policy makers through process studies and model improvements in concert with climate model research institutions.
- Construct a comprehensive data system integrating GCOM products, other satellite data, and in-situ measurements.
- Contribute to operational users including weather forecasting, fishery, and maritime agencies by providing near-real-time data.
- Investigate and develop advanced products valuable for understanding of climate change and water cycle studies.

Detailed explanations of the objectives are as follows.

(1) Understanding global environment changes

A) Establish and demonstrate a global, long-term Earth-observing system that is able to observe valuable geophysical parameters for understanding global climate variability and water cycle mechanisms.

B) Contribute to improving climate prediction models by providing accurate values of model parameters.

C) Clarify sinks and sources of greenhouse gases.

D) Contribute to validating and improving climate prediction models by forming a collaborative framework with climate model institutions and providing long-term geophysical datasets to them.

E) Detect trends of global environment changes (e.g., global warming, vegetation changes, desertification, variation of atmospheric constituents, wide area air pollution, and depletion of ozone layers) from long-term variability of geophysical parameters by extracting short-term (three- to six-year) natural variability.

F) Advance process studies of Earth environmental changes using observation data.

G) Estimate radiative forcing, energy and carbon fluxes, and albedo by combining satellite geophysical parameters, ground in-situ measurements, and models.

H) Advance the understanding of the Earth's system through the activities above.

I) Contribute to an international environmental strategy utilizing the results above.

(2) Direct contribution to improving people's lives

A) Improvement of weather forecast accuracy (particularly typhoon track prediction, localized severe rain, etc.).

B) Improvement of forecast accuracy for unusual weather and climate.

C) Improvement of water-route and maritime information.

D) Provision of fishery information.

E) Efficient coastal monitoring.

F) Improved yield prediction of agricultural products.

G) Monitoring and forecasting air pollution including yellow dust.

H) Observation of volcanic smoke and prediction of the extent of the impact.

I) Detection of forest fires.

3. Observing Systems

3.1. Overall concept

As mentioned in the previous section, the entire GCOM will consist of two satellite series spanning three generations. However, a budget will be approved for each satellite. Currently, only the GCOM-W satellite has been launched as the first satellite in the GCOM series. Both GCOM-W and GCOM-C satellites will be medium-size platforms that are smaller than the ADEOS-II satellite. This is to reduce the risk associated with large platforms having valuable and multiple observing instruments. Also, since the ADEOS-II problem was related to the solar paddle, a dual solar-paddle design was adopted for both satellites. To assure data continuity and consistent calibration, follow-on satellites will be launched so as to overlap the preceding satellite by one year. The concept is summarized in Fig. 1.

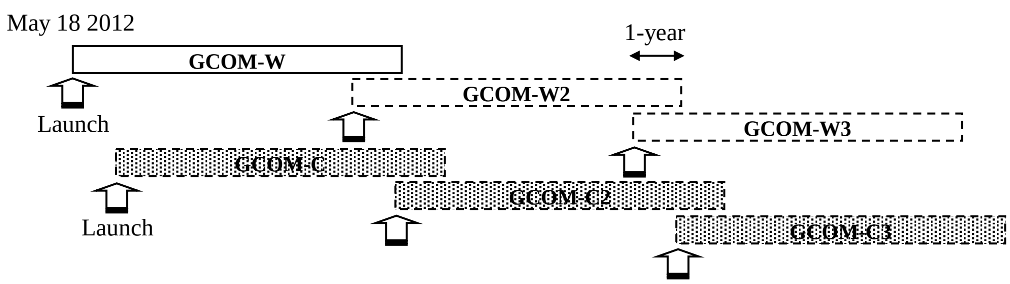

Figure 1: **GCOM Concept**

3.2. GCOM-W and AMSR2 instrument

Figure 2 presents an overview of the GCOM-W satellite; its major characteristics are listed in Table 1. GCOM-W will carry AMSR2 as the sole onboard mission instrument. The satellite will orbit at an altitude of about 700km and will have an ascending node local time of 13:30, to maintain consistency with Aqua/AMSR-E observations.

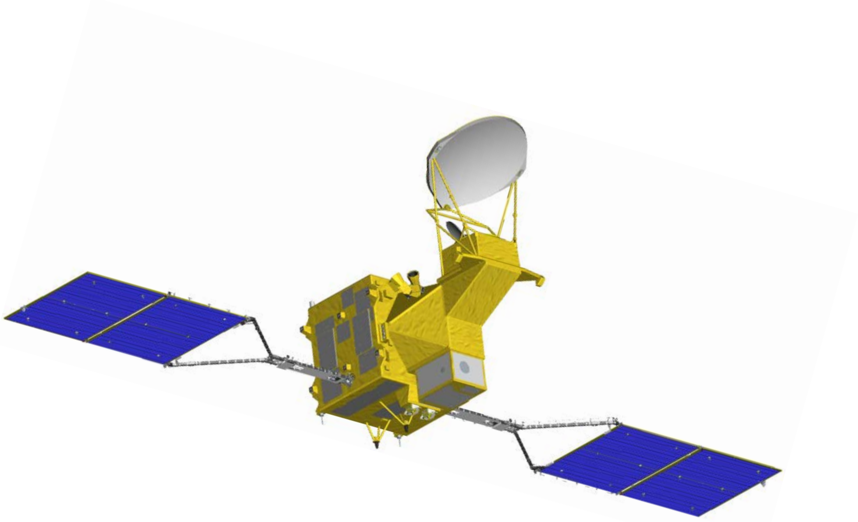

Figure 2: **Overview of GCOM-W Satellite**

Table 1: **Major Characteristics of GCOM-W Satellite**

Instrument	Advanced Microwave Scanning Radiometer-2 (AMSR2)
Orbit	Sun-synchronous orbit Altitude: 700km (over the equator)
Size	5.1m (X) * 17.5m (Y) * 3.4m (Z) (on-orbit)
Mass	1991kg
Power	More than 3880W (EOL)
Launch	May 18, 2012 by H-IIA Rocket
Design Life	5 years
Status	Phase-D

Figure 1 presents an overview of the AMSR2 instrument in two different conditions. Also, basic characteristics including center frequency, bandwidth, polarization, instantaneous field of view (FOV), and sampling interval are indicated in Table 2. The basic concept is almost identical to that of AMSR-E: a conical scanning system with a large offset parabolic antenna, feed horn cluster to realize multi-frequency observation, external calibration with two temperature standards, and total-power radiometer systems. The 2.0m diameter antenna, which is larger than that of AMSR-E, provides better spatial resolution at the same orbit altitude of around 700km. The antenna will be developed based on the experience gained from the 2.0m diameter antenna for ADEOS-II AMSR except the deployment mechanism. For the C-band receiver, we adopted additional 7.3GHz channels for possible mitigation of radio-frequency interference. An incidence angle of 55 degrees (over the equator) was selected to maintain consistency with AMSR-E. The swath width of 1450km and the selected satellite orbit will provide almost complete coverage of the entire Earth’s surface within two days independently for ascending and descending observations.

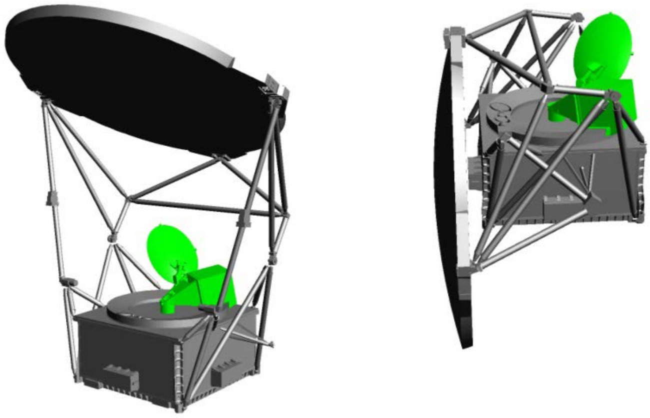

Figure 3: **Sensor Unit of AMSR2 Instrument in Deployed (left) and Stowed (right) Conditions.**

Table 2: **Major Characteristics of AMSR2 Instrument**

Parameter	**Performance and characteristics**					
Center Frequency (GHz)	6.925/7.3	10.65	18.7	23.8	36.5	89.0
Bandwidth (MHz)	350	100	200	400	1000	3000
Polarization	Vertical and Horizontal polarization					
NEΔT (K) [1]	< 0.34/0.43	< 0.70	< 0.70	< 0.60	< 0.70	< 1.20/1.40 [2]
Dynamic range (K)	2.7 to 340					
Nominal incidence angle (deg.)	55.0					55.0/54.5 [2]
Beam width (deg.)	1.8	1.2	0.65	0.75	0.35	0.15
IFOV (km) Cross-track x along-track	35x62	24x42	14x22	15x26	7x12	3x5
Approximate sampling interval (km)	10					5
Swath width (km)	> 1450					
Digital quantization (bits)	12					
Scan rate (rpm)	40					

3.3. GCOM-C and SGLI instrument

Figure 4 gives an overview of the GCOM-C satellite; its major characteristics are listed in Table 3. GCOM-C will carry SGLI as the sole mission onboard instrument. The satellite will orbit at an altitude of about 800km; the descending node local time will be 10:30, to maintain a wide observation swath and reduce cloud interference over land.

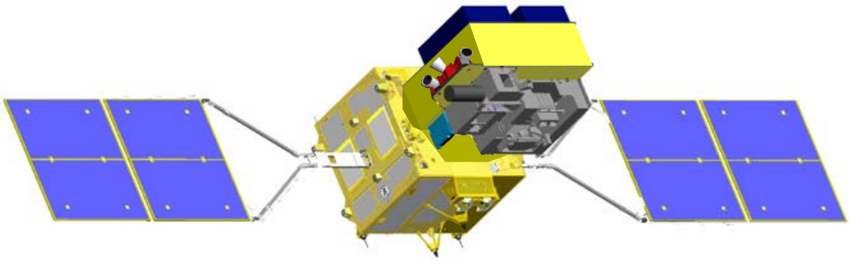

Figure 4: **Overview of GCOM-C Satellite**

Table 3: **Major Characteristics of GCOM-C Satellite**

Instrument	Second-generation Global Imager (SGLI)
Orbit	Sun-synchronous orbit Altitude: 798km (over the equator)
Size	4.6m (X) * 16.3m (Y) * 2.8m (Z) (on orbit)
Mass	2093kg
Power	More than 4000W (EOL)
Launch	JFY2016 by H-IIA Rocket
Design Life	5 years
Status	Phase-C

The SGLI instrument has two major new features: 250m spatial resolution for most of the visible channels and polarization/multidirectional observation capabilities. The 250m resolution will provide enhanced observation capability over land and coastal areas where the influences of human activity are most obvious. The polarization and multidirectional observations will enable us to retrieve aerosol information over land. Precise observation of global aerosol distribution is a key for improving climate prediction models.

SGLI consists of two major components: the Infrared Scanner (IRS) and the Visible and Near-infrared Radiometer (VNR). An overview of the SGLI instrument is shown in Fig. 5 for the entire radiometer layout, IRS, and VNR components. Also, requirements for sensor performance are listed in Tables 4 and 5. VNR can be further divided into two components: VNR-Non Polarized (VNR-NP) and VNR-Polarized (VNR-P). VNR-NP and VNR-P are the 11-channel multi-band radiometer and the polarimeter with three polarization angles (0, 60, and 120 degrees). VNR-P has a tilting function to meet the scatter angle requirement from aerosol observation. The IRS is an infrared radiometer covering wavelengths from 1μm to 12μm. It consists of short infrared (SWI; 1.05 to 2.21μm) and thermal infrared (TIR 10.8 and 12.0μm) sensors. It employs a scanning mirror system with a 45-degree tilted flat mirror rotating continuously to realize an 80-degree observation swath and calibration measurement in every scan.

Through intensive discussions and optimizing studies, the number of SGLI channels was decreased from the 36 channels of GLI aboard ADEOS-II to 19 channels, while the number of SGLI standard products will increase compared to those of GLI.

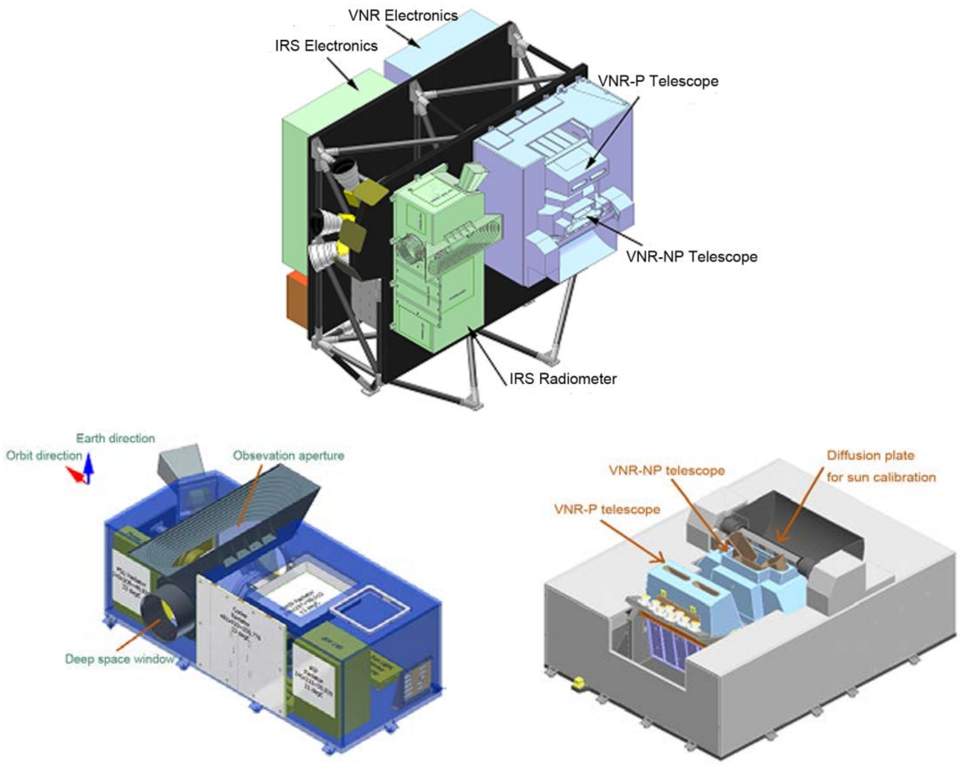

Figure 5: **Overview of SGLI Radiometer Layout (upper), IRS Instrument (lower-left), and VNR Radiometers (lower-right).**

Table 4: **SGLI Major Performance Requirements**

Item	Requirement
Spectral Bands	VNR-NP : 11CH 380-865nm VNR-P : 2CH 673.5, 868.5nm / 0, 60, 120deg Polarization IRS SWI : 4CH 1.05-2.21μm IRS TIR : 2CH 10.8, 12.0μm
Scan Angle	VNR-NP : 70deg (Push broom scanning) VNR-P : 55deg (Push broom scanning) IRS SWI/TIR : 80deg (45deg rotation mirror scanning)
Swath width	1150km for VNR-NP/P 1400km for IRS SWI/TIR
Instantaneous field of view (IFOV) at nadir	VNR-NP : 250m VNR-P : 1000m IRS SWI : 250m(SW3CH), 1000m(SW1,2,4CH) IRS TIR : 500m (250m: option)
Observing direction	±45 degrees in along track direction for VNR-P Nadir for VNR-NP, IRS SWI, and IRS TIR
Quantization	12bit
Absolute Calibration Accuracy	VNR : ≤3% IRS : ≤5% TIR : ≤0.5K
Lifetime	5 Years

Table 5: **SGLI Observation Requirement Details**

	CH	λ	Δλ	IFOV	SNR	L (for SNR)
		nm: VNR, IRS SWI μm: IRS TIR		m	SNR: VNR, IRS SWI NEΔT(K): IRS TIR	$W/m^2/sr/\mu m$
VNR-NP	VN1	380	10	250	250	60
	VN2	412	10	250	400	75
	VN3	443	10	250	300	64
	VN4	490	10	250	400	53
	VN5	530	20	250	250	41
	VN6	565	20	250	400	33
	VN7	673.5	20	250	400	23
	VN8	673.5	20	250	250	25
	VN9	763	12	250	1200 (@1km IFOV)	40
	VN10	868.5	20	250	400	8
	VN11	868.5	20	250	200	30
VNR-P	P1	673.5	20	1000	250	25
	P2	868.5	20	1000	250	30
IRS SWI	SW1	1050	20	1000	500	57
	SW2	1380	20	1000	150	8
	SW3	1630	200	250	57	3
	SW4	2210	50	1000	211	1.9
IRS TIR	T1	10.8	0.74	1000/500/250	0.2 (@500m IFOV)	300 (K)
	T2	12.0	0.74	1000/500/250	0.2 (@500m IFOV)	300 (K)

4. Products

Geophysical products made available by GCOM-W and GCOM-C are listed in Tables 6, 7, and 8. There are two categories of data products: standard product and research product. A “standard” product is defined as a product with proven accuracy that is to be operationally processed and distributed. In contrast, a “research” product is a prototype for a standard product and is processed on a research basis. Both tables indicate standard products with shading.

Table 6: **Standard Geophysical Products of GCOM-W**

Product	Areas	Resolution (km)	Accuracy [1]			Range	
			Release threshold	Standard	Goal		
Integrated water vapor	Global, over ocean	15	±3.5 kg/m^2	±3.5 kg/m^2	±2.0 kg/m^2	0-70 kg/m^2	Vertically integrated (columnar) water vapor amount. Except sea ice and precipitating areas.
Integrated cloud liquid water	Global, over ocean	15	±0.10 kg/m^2	±0.05 kg/m^2	±0.02 kg/m^2	0-1.0 kg/m^2	Vertically integrated (columnar) cloud liquid water. Except sea ice and precipitating areas.
Precipitation	Global, except cold latitudes	15	Ocean ±50 % Land ±120 %	Ocean ±50% Land ±120 %	Ocean ±20% Land ±80 %	0-20 mm/h	Surface precipitation rate. Accuracy is defined as relative error (ratio of root-mean-square error to average precipitation rate) in 50km grid average.
Sea surface temperature	Global, over ocean	50	±0.8 °C	±0.5 °C	±0.2 °C	-2-35 °C	Except sea ice and precipitating areas. Goal accuracy is defined as monthly mean bias error in 10 degrees latitudes.
Sea surface wind speed	Global, over ocean	15	±1.5 m/s	±1.0 m/s	±1.0 m/s	0-30 m/s	Except sea ice and precipitating areas.
Sea ice concentration	Polar region, over ocean	15	±10 %	±10 %	±5 %	0-100 %	Accuracy is expressed in absolute value of sea ice concentration (%).
Snow depth	Land	30	±20 cm	±20 cm	±10 cm	0-100 cm	Except ice sheets and dense forest areas. Accuracy is expressed in snow depth and defined as mean absolute error of instantaneous observations.
Soil moisture	Land	50	±10 %	±10 %	±5 %	0-40 %	Volumetric water content over global land areas including arid and cold regions, except areas covered by vegetation with 2kg/m^2 water equivalent. Accuracy is defined as mean absolute error of instantaneous observations.

1 Accuracy is defined as root-mean-square error of instantaneous values unless otherwise stated. Assumed validation methodologies are not explained here.

Table 7: **Research Products of GCOM-W**

Products	Area	Resolution (km)	Target accuracy	Range
All-weather sea surface wind speed	Ocean	60	± 7 m/s	0 - 70 m/s
High-resolution (10-GHz) sea surface temperature	Ocean	30	± 0.8 °C	9 - 35 °C
Soil moisture and vegetation water content based on the land data assimilation	Africa, Australia	25	soil moisture: ± 8% vegetation water: ± 1 kg/m^2	soil moisture: 0 - 100 % vegetation water: 0 - 2 kg/m^2
Land surface temperature	Land	15	forest area: ± 3 °C nondense vegetation: ± 4 °C	0 - 50 °C
Vegetation water content	Land	10	± 1 kg/m^2	0 - 4 kg/m^2
High resolution sea ice concentration	Ocean in high latitude	5	± 1 %	0 - 100 %
Thin ice detection	Okhotsk sea	15	± 80 %	N/A
Sea ice moving vector	Ocean in high latitude	50	2 components: 3 cm/s	0 - 40 cm/s

Table 8: **Geophysical Products of GCOM-C (1/3)**

Area	*Group*	*Product*	*Category*	*Developer*	*Day/night*	*Production unit*	*Grid size*	*Release threshold**2	*Standard accuracy**2	*Target accuracy**2
common	Radiance	TOA radiance (including system geometric correction)	Standard	JAXA	TIR and land 2.2μm: both, Other VNR, SWI: daytime (+special operation)	Scene	VNR,SWI Land/coast: 250m, offshore: 1km, polarimetory:1km TIR Land/coast: 500m, offshore: 1km	Radiometric 5% (absolute)*3 Geometric<1 pixel	VNR,SWI: 5% (absolute), 1% (relative) *3 TIR: 0.5K (@300K) Geometric<0.5 pixel	VNR,SWI: 3% (absolute), 0.5% (relative) *3 TIR: 0.5K (@300K) Geometric<0.3 pixel
Land	Surface reflectance	Precise geometric correction	Standard	JAXA	Both	Tile, Global (mosaic 1, 8 days, month)	250m	<1pixel	<0.5pixel	<0.25pixel
		Atmospheric corrected reflectance (incl. cloud detection)	Standard	JAXA	Daytime	Tile , Global (1, 8 days, month)	250m	0.3 (<=443nm), 0.2 (>443nm) (scene) *7	0.1 (<=443nm), 0.05 (>443nm) (scene) *7	0.05 (<=443nm), 0.025 (>443nm) (scene)*7
	Vegetation and carbon cycle	Vegetation index	Standard	PI/JAXA	Daytime	Tile , Global (1, 8 days, month)	250m	Grass: 25%, forest: 20% (scene)	Grass: 20%, forest: 15% (scene)	Grass: 10%, forest: 10% (scene)
		fAPAR	Standard	PI/JAXA				Grass: 50%, forest: 50%	Grass: 30%, forest:20%	Grass: 20%, forest: 10%
		Leaf area index	Standard	PI/JAXA				Grass: 50%, forest: 50%	Grass: 30%, forest:30%	Grass: 20%, forest: 20%
		Above-ground biomass	Standard	PI	Daytime	Tile , Global (1, 8 days, month)	1km	Grass: 50%, forest: 100%	Grass: 30%, forest: 50%	Grass: 10%, forest: 20%
		Vegetation roughness index	Standard				1km	Grass and forest: 40% (scene)	Grass and forest: 20% (scene)	Grass and forest: 10% (scene)
		Shadow index	Standard				250m, 1km	Grass and forest: 30% (scene)	Grass and forest: 20% (scene)	Grass and forest: 10% (scene)
	Temperature	Surface temperature	Standard	PI	Both	Tile , Global (1, 8 days, month)	500m	<3.0K (scene)	<2.5K (scene)	<1.5K (scene)
	Application	Land net primary production	Research	PI	Daytime	Global (month, year)	1km	N/A	N/A	30% (yearly)
		Water stress trend	Research	PI	N/A	Tile , Global (1, 8 days, month)	500m	N/A	N/A	10% *13 (error judgment rate)
		Fire detection index	Research	PI	Both*12	Scene or Tile	500m	N/A	N/A	20% *14 (error judgment rate)
		Land cover type	Research	PI/JAXA	Daytime	Global (month, season)	250m	N/A	N/A	30% (error judgment rate)
		Land surface albedo	Research	JAXA/PI	N/A	Tile , Global (1, 8 days, month)	1km	N/A	N/A	10%
Atmosphere	Cloud	Cloud flag/Classification	Standard	PI	Both	Tile , Global（1, 8 day, month）	1km	10% (with whole-sky camera)	Incl. below cloud amount	Incl. below cloud amount
		Classified cloud fraction	Standard		Daytime	Global（1, 8 day, month）	1km (Tile), 0.1deg (global)	20% (on solar irradiance)*9	15% (on solar irradiance)*9	10% (on solar irradiance)*9
		Cloud top temp/height	Standard		Both	Tile , Global（1, 8 day, month）		1K*4	3K/2km (top temp/height)*5	1.5K/1km (temp/height)*5
		Water cloud OT/effective radius	Standard		Daytime	Tile , Global（1, 8 day, month）		10%/30% (Cloud OT/radius)*6	100% as CLW*7	50%*7 / 20%*8
		Ice cloud optical thickness	Standard		Daytime	Tile , Global（1, 8 day, month）		30%*6	70%*8	20%*8
		Water cloud geometrical thickness	Research	PI	Daytime	Tile , Global（1, 8 day, month）		N/A	N/A	300m
	Aerosol	Aerosol over the ocean	Standard	JAXA	Daytime	Tile , Global（1, 8 day, month）		0.1 (Monthly τa_670,865)*10	0.1(scene τa_670,865)*10	0.05 (scene τa_670,865)
		Land aerosol by near UV	Standard		Daytime	Tile , Global（1, 8 day, month）		0.15 (Monthly τa_380)*10	0.15 (scene τa_380)*10	0. 1(scene τa_380)
		Aerosol by Polarization	Standard	PI	Daytime	Tile , Global（1, 8 day, month）		0.15 (Monthly τa_670,865)*10	0.15 (scene τa_670,865)*10	0.1 (scene τa_670,865)
	Radiation budget	Long-wave radiation flux	Research	TBD	Daytime	Tile , Global（1, 8 day, month）		N/A	N/A	Downward 10W/m2, upward 15W/m2 (monthly)
		Short-wave radiation flux	Research	JAXA/PI	Daytime	Tile , Global（1, 8 day, month）		N/A	N/A	Downward 13W/m2, upward 10W/m2

Table 8: **Geophysical Products of GCOM-C (2/3)**

Area	*Group*	*Product*	*Category*	*Developer*	*Day/night*	*Production unit*	*Grid size*	*Release threshold*[*2]	*Standard accuracy*[*2]	*Target accuracy*[*2]
Ocean	Ocean color	Normalized water-leaving radiance (incl. cloud detection)	Standard	PI	Daytime	Scene, Global (1, 8 days, month)	Coast: 250m Offshore: 1km Global: 4-9km	60% (443~565nm)	50% (<600nm) 0.5W/m^2/str/um (>600nm)	30% (<600nm) 0.25W/m^2/str/um (>600nm)
		Atmospheric correction parameter	Standard					80% (AOT@865nm)	50% (AOT@865nm)	30% (AOT@865nm)
		Photosynthetically available radiation	Standard	JAXA/ PI	Daytime	Scene, Global (1, 8 days, month)		20% (10km/month)	15% (10km/month)	10% (10km/month)
		Euphotic zone depth	Research	PI	Daytime	Scene, Global (1, 8 days, month)		N/A	N/A	30%
	In-water	Chlorophyll-a concentration	Standard	JAXA/PI	Daytime	Scene, Global (1, 8 days, month)		–60 to +150% (offshore)	–60 to +150%	–35 to +50% (offshore), –50 to +100% (coast)
		Total suspended matter concentration	Standard	PI				–60 to +150% (offshore)	–60 to +150%	–50 to +100%
		Colored dissolved organic matter	Standard	PI				–60 to +150% (offshore)	–60 to +150%	–50 to +100%
		Inherent optical properties	Research	PI	Daytime	Scene, Global (1, 8 days, month)		N/A	N/A	a (440): RMSE<0.25, bbp (550): RMSE<0.25
	Temperature	Sea-surface temperature	Standard	JAXA	Both	Scene, Global (1, 8 days, month)	Coast: 500m Others: Same as above	0.8K (daytime)	0.8K (day & night time)	0.6K (day and night time)
	Application	Ocean net primary productivity	Research	PI	Daytime	Scene, Global (1, 8 days, month)	Coast: 500m Others: Same as above	N/A	N/A	70% (monthly)
		Phytoplankton functional type	Research	PI	Daytime	Scene, Global (1, 8 days, month)	Coast: 250m Others: Same as above	N/A	N/A	error judgment rate of large/ small phytoplankton dominance<20%; or error judgment rate of the dominant phytoplankton functional group <40%
		Red tide	Research	PI	Daytime	Scene, Global (1, 8 days, month)		N/A	N/A	error judgment rate <20%
		multi sensor merged ocean color	Research	JAXA/PI	Daytime	Area, Global (1, 8 days, month)	Coast: 250m Offshore: 1km	N/A	N/A	–35 to +50% (offshore), –50 to +100% (coast)
		multi sensor merged SST	Research	TBD	Both			N/A	N/A	0.8K (day & night time)
Cryosphere	Area/ distribution	Snow and Ice covered area (incl. cloud detection)	Standard	PI/JAXA	Daytime	Tile, Global (1, 8 days, month)	250m (Tile), 1km (global)	10% (vicarious val with other sat. data)	7%	5%
		Okhotsk sea-ice distribution	Standard		Daytime	Area (1day)	250m	10%	5%	3%
		Snow and ice classification	Research		Daytime	Global (8 days, month)	1km	N/A	N/A	10%
		Snow covered area in forests and mountains	Research	JAXA	Daytime	Area (1, 8 days)	250m	N/A	N/A	30%
	Surface properties	Snow and ice surface Temperature	Standard	PI	Daytime	Tile, Global (1, 8 days, month)	500m (Tile), 1km (global)	5K (vicarious val with other sat. data and climatology)	2K	1K
		Snow grain size of shallow layer	Standard		Daytime	Tile, Global (1, 8 days, month)	250m (Tile), 1km (global)	100% (vicarious val. with climatology between temp-size)	50%	30%
		Snow grain size of subsurface layer	Research		Daytime	Tile, Global (1, 8 days, month)	1km	N/A	N/A	50%
		Snow grain size of top layer	Research		Daytime	Tile, Global (1, 8 days, month)	250m (Tile), 1km (global)	N/A	N/A	50%
		Snow and ice albedo	Research	PI	Daytime	Global (1, 8 days, month)	1km	N/A	N/A	7%

Table 8: **Geophysical Products of GCOM-C (3/3)**

Area	*Group*	*Product*	*Category*	*Developer*	*Day/night*	*Production unit*	*Grid size*	*Release threshold*[*2]	*Standard accuracy*[*2]	*Target accuracy*[*2]
Cryosphere	Surface properties	Snow impurity	Research	PI	Daytime	Tile, Global (1, 8 days, month)	250m (Tile), 1km (global)	N/A	N/A	50%
		Ice sheet surface roughness	Research	PI	Daytime	Area (Season)	1km	N/A	N/A	0.05 *15
	Boundary	Ice sheet boundary monitoring	Research	JAXA	Daytime	Area (Season)	250m	N/A	N/A	<500m

Common notes:
*1. Heritage levels from ADEOS-II/GLI study are shown by A-C; A: high heritage, B: Remaining issues, C: new or many issues remaining to be resolved
*2. The “release threshold” is minimum levels for the first data release at one year from launch. The "standard" and "research" accuracies correspond to full and extra success criteria of the mission. Accuracies are basically shown by RMSE.

Radiance data notes:
*3. Absolute error is defined as offset + noise; relative error is defined as relative errors among channels, FOV, and so on. Release threshold of radiance is defined as estimated errors from vicarious, onboard solar diffuser, and onboard blackbody calibration because of lack of long-term moon samples

Atmosphere notes:
*4. Vicarious val. on sea-surface temperature and comparison with objective analysis data
*5. Inter comparison with airplane remote sensing on water clouds of middle optical thickness
*6. Release threshold is defined by vicarious val. with other satellite data (e.g., global monthly statistics in the mid-low latitudes)
*7. Comparison with cloud liquid water by in-situ microwave radiometer
*8. Comparison with optical thickness by sky-radiometer (the difference can be large due to time-space inconsistence and large error of the ground measurements)
*9. Comparison with in-situ observation on monthly 0.1-degree
*10. Estimated by experience of aerosol products by GLI and POLDER

Land data notes:
*11. Defined with land reflectance~0.2, solar zenith<30deg, and flat surface. Release threshold is defined with AOT@500nm<0.25
*12. Night time 250m product can be produced by special observation requests of 1.6μm channel
*13. Evaluate in semiarid regions (steppe climate, etc.)
*14. Fires >1000K occupying >1/1000 on 1km pixel at night (using 2.2um of 1 km and thermal infrared channels)

Cryosphere notes:
*15. Defined as height/width of the surface structures

APPENDIX 2

OVERVIEW OF THE GLOBAL PRECIPITATION MEASUREMENT (GPM) AND THE TROPICAL RAINFALL MEASURING MISSION (TRMM)

1. Introduction

"Precipitation" is one of most important environmental parameters. Changes in its amount and distribution may affect our everyday life, and they may cause serious damages to human lives and properties. 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. Precipitation is a true global variable that determines the general circulation through latent heating, which is an "engine" for circumglobal winds, and reflects climate changes. It is a key component of air-sea interaction and eco-hydrometeorological modeling.

Although there is no doubt that precipitation is such an important component of our environment, it is one of the least known physics components of cloud, weather and climate prediction models. Because of its large variability in space and time, its distribution over the globe is not accurately known. Knowledge of the spatial and temporal distribution of global precipitation is a key to improving our understanding of weather and climate systems.

The Tropical Rainfall Measuring Mission (TRMM) satellite, which is still flying and archiving tropical/subtropical rainfall data more than 11 years, is a joint Japan-US mission. TRMM, launched in the end of November 1997 by the Japanese H-II rocket, focuses on measuring tropical/subtropical rainfall and their diurnal variations, and covers latitude from 35S to 35N. TRMM has three precipitation sensors: the Precipitation Radar (PR), the world first space-borne precipitation radar developed by Japan, and the TRMM Microwave Imager (TMI) and the Visible Infrared Scanner (VIRS) developed by the U.S., which enables observation of rainfall structures by multiple sensors, simultaneously.

Because of the success of the TRMM satellite, several requirements for the successor mission emerged from the science and operational user community. The Global Precipitation Measurement (GPM) mission was proposed to fulfill those requirements. 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 modeling, and understanding of water cycles. Its feasibility has been studied at Goddard Space Flight Center of the National Aeronautics and Space Administration (NASA) and the Japan Aerospace Exploration Agency (JAXA). Accurate measurement of precipitation will be achieved using the Dual-frequency Precipitation Radar (DPR) installed on the GPM Core Observatory. The DPR on the GPM Core Observatory is being developed by JAXA and the National Institute of Information and Communications Technology (NICT).

2. The Tropical Rainfall Measuring Mission (TRMM)

The Tropical Rainfall Measuring Mission (TRMM) satellite (Figure 1) was launched by H-II rocket No. 6 in November 1997, and completed its mission in April 2015.

Major characteristics of the TRMM satellite are described in Table 1. TRMM is joint mission between Japan (JAXA (former NASDA) and NICT (former CRL)) and the U.S. (NASA). The major objective of TRMM is to determine accurate rainfall amount associated with tropical convective activities, which is a drive source of global atmospheric circulation. To this purpose, the TRMM satellite focuses on rainfall observation, and carries the world's first satellite-borne Precipitation Radar (PR) developed by Japan, in addition to conventional instruments such as infrared imager and microwave imager (TRMM Microwave Imager: TMI). The combination use of PR and TMI has greatly improved the estimation of rainfall amount and has succeeded in observing climate changes, as with El Niño and La Niña. Since the three-dimensional structure of rainfall over the land and ocean can be derived from PR, TRMM has also revealed the three-dimensional structure of typhoons over the ocean, which was rarely observed before TRMM. The success of TRMM shows the potential of satellite remote sensing contributions for understanding the water cycle on Earth and improving weather forecasts.

The TRMM satellite also targets rainfall observation in the tropics and sub-tropics. In order to measure tropical rainfall that has large diurnal variation, it flies in non-sun-synchronous orbit with an inclination angle of 35°. Although the designed lifetime of the satellite was about 3 years, the satellite altitude was boosted from 350 km to 402.5 km in August 2001 to extend the lifetime by reducing atmospheric drag. In March 2009, more than 11 years after the satellite's launch, it continues its excellent observation and provides valuable meteorological and climatological data relating to precipitation, through long-term observation of the current status of rainfall in the tropics and sub-tropics, for understanding water cycle mechanisms.

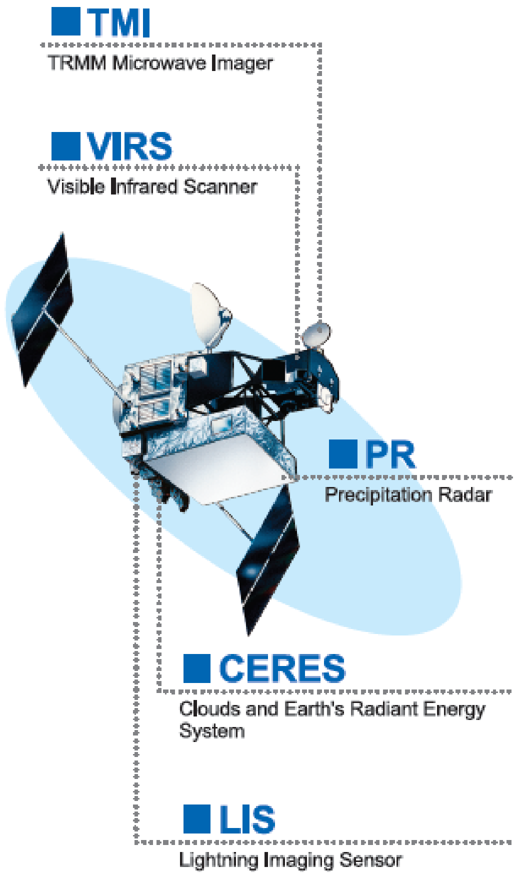

Figure 1 Overview of the TRMM Satellite and the Five on board Sensors

Table 1 Major Characteristics of the TRMM Satellite

Orbit	Non-sun-synchronous circular orbit
Inclination	Approx. 35 degrees
Altitude	Approx. 350 km (402.5 km since August 24, 2001)
Launch date	November 28, 1997 6:54 AM (JST)
Design life	3 years and 2 months
Mission instrument	Precipitation Radar (PR) TRMM Microwave Imager (TMI) Visible Infrared Scanner (VIRS) Lightning Imaging Sensor (LIS) Clouds and Earth's Radiant Energy System (CERES)

3. The Global Rainfall Measurement (GPM)

3.1 From TRMM to GPM

As accuracy of satellite precipitation estimates improves and observation frequency increases, application of those data to societal benefit areas, such as weather forecasts and flood predictions, is expected, in addition to research of precipitation climatology to analyze precipitation systems. There is, however, limitation on single satellite observation in coverage and frequency. Therefore, the Global Precipitation Measurement (GPM) mission was proposed under international collaboration to fulfill various user requirements that cannot be achieved by the single TRMM satellite.

One major characteristic of GPM as follow-on and expansion of TRMM is to operate the GPM Core Observatory, which carries an active precipitation radar and a passive microwave radiometer, with a non-sun-synchronous orbit as a calibrator to other satellites. The other is a collaboration with a constellation of several satellites developed by each international partner (space agency) that carries passive microwave radiometers and/or microwave sounders, to increase observation frequency. Although the TRMM satellite focused on observation of the tropics, the GPM mission covers broader areas, including high latitudes.

3.2 Concept of the GPM **M**ission

TRMM is single satellite mission for scientific research. On the other hand, the GPM mission (Fig. 2) is an international mission to achieve high-accurate and high-frequent rainfall observation over a global area. GPM is composed of a TRMM-like non-sun-synchronous orbit satellite (GPM Core Observatory) and multi-satellites carrying microwave radiometer instruments (constellation satellites). The GPM Core Observatory carries the Dual-frequency Precipitation Radar (DPR), which is being developed by JAXA and NICT, and the GPM Microwave Imager (GMI) provided by NASA, and will achieve more accurate but narrower observation as a calibrator to other constellation satellites. Constellation satellites, which carry a microwave imager and/or sounder and are planned to be launched around 2014-2018 by each partner agency for its own purpose, and will contribute to extending coverage and increasing frequency.

To take over the results that have been achieved by TRMM and to facilitate development of those results, the GPM mission is planned to meet user requirements that cannot be achieved by TRMM or are expected to be improved in GPM: 1) expansion of observation coverage; 2) increase of observation frequency; and 3) improvement of observation accuracy.

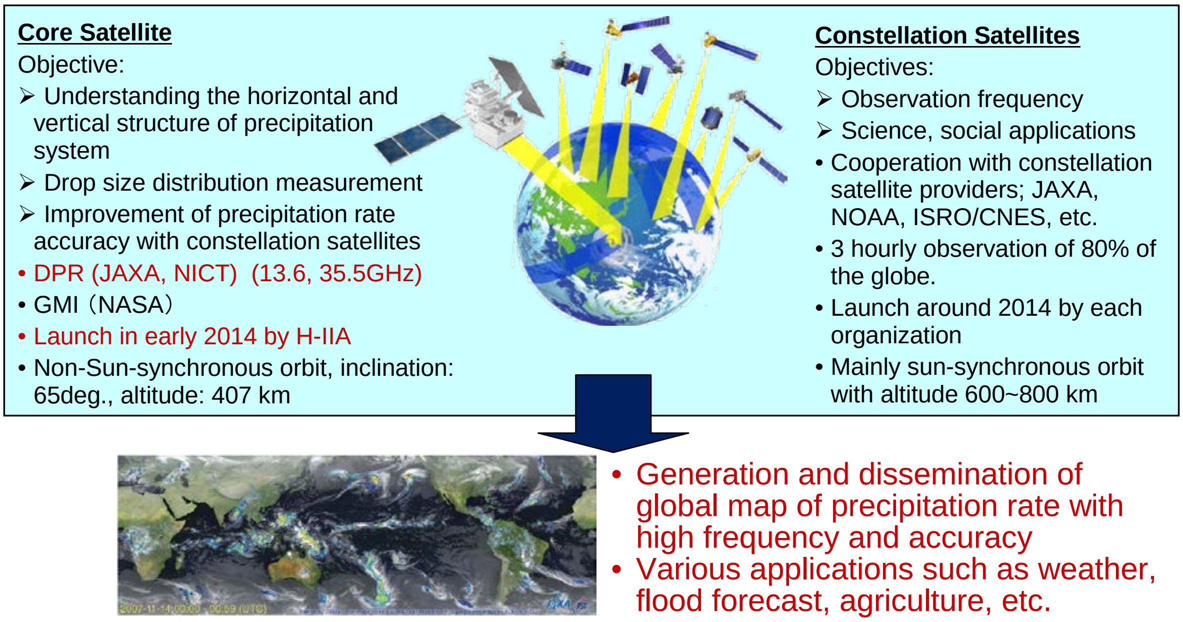

Figure 2 Overview of the GPM Mission

3.3 Overview of the GPM Core Observatory

The GPM Core Observatory (Table 2 and Figure 3), which is being jointly developed by Japan and the U.S., was launched in February 2014. The core satellite carries a Dual-frequency Precipitation Radar (DPR) developed by Japan, and a GPM Microwave Imager (GMI) developed by U.S. The orbit of the core satellite is non-sun-synchronous with an inclination angle of 65°. This orbit was selected to meet certain requirements, such as to measure diurnal variation of rainfall in mid- and high-latitudes as well as the tropics for around 2 months.

Table 2 Major Characteristics of the GPM Core Observatory

Orbit	Non-sun-synchronous
Inclination	65 degrees
Altitude	407 km
Launch date	February 28, 2014 03:36 AM (JST)
Mission life	3 years (target: 5 years)
Mission instrument	Dual-frequency Precipitation Radar (DPR) GPM Microwave Imager (GMI)

The Dual-frequency Precipitation Radar (DPR) on board the GPM Core Observatory is composed of two radars: a Ku-band (13.6-GHz) Precipitation Radar (KuPR) and a Ka-band (35.5-GHz) Precipitation Radar (KaPR). KaPR aims at sensitive observation, and can detect weaker rainfall and snowfall that cannot be measured by KuPR. Since KuPR can detect heavier rainfall, simultaneous observation of KaPR and KuPR will enable accurate measurement of precipitation from heavy rainfall in the tropics to weak snowfall in high latitudes. Rain echo is affected by precipitation attenuation, and its amount depends on radar frequency and raindrop size. By matching position of radar beams and timing of transmitted pulses for KuPR and KaPR, and measuring precipitation particles at the same place simultaneously by dual-frequency, size of precipitation particles (raindrop size distribution) can be estimated by differences in precipitation attenuation. This information cannot be obtained by single-frequency radar, such as TRMM's PR, and will improve accuracy of precipitation estimation. It is also expected to identify rainfall and snowfall by using differences in precipitation attenuation for dual-frequency.

The GPM Microwave Imager (GMI) instrument on board the GPM Core Observatory is a multi-channel conical-scanning microwave radiometer developed by NASA, and it is based on the TMI on board the TRMM satellite. The major role of the GMI is to improve accuracy of rainfall/snowfall estimates by simultaneous observation with the DPR, and to work as a bridge between highly accurate observation by the core satellite and frequent observations by the constellation satellites. GMI is also expected to serve as a 'radiometric standard' for the other microwave radiometers on board the GPM constellation satellites, and to reduce differences in rain rate estimation arising from biases of instruments. The GMI is characterized by thirteen microwave channels ranging in frequency from 10 GHz to 183 GHz. In addition to carrying channels similar to those on the TRMM Microwave Imager (TMI), the GMI carries four high frequency, millimeter-wave, channels of about 166-GHz ('window' channel) and 183-GHz (water vapor channel). Addition of those high frequency channels is expected to contribute to improvements in accuracy of weak rainfall and snowfall estimates, especially over the ocean and land in high-latitudes. With a 1.2 m diameter antenna, the GMI will provide significantly improved spatial resolution over TMI.

The roles of the GPM primary satellite are to collect as much microphysical information as possible for accurate rain estimation by performing synchronous observation with the GMI and the DPR and to provide calibration standards for the other microwave radiometers on the constellation satellites.

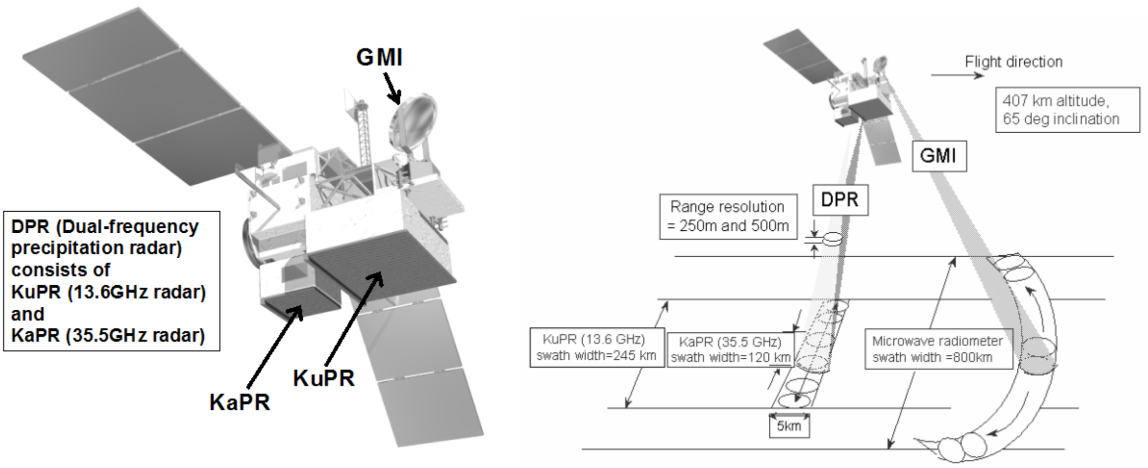

Figure 3 Overview of the GPM Core Satellite and Concept of Precipitation Observation

3.4 Collaboration with Constellation Satellites

In the case of low orbital satellites, such as TRMM and Aqua, single-satellite cannot observe frequently at each local point. To overcome this weakness and achieve frequent observation, the GPM mission will work with other satellite missions in the world. Figure 4 shows how the observation area covered in 3 hours by microwave radiometers on polar-orbiting satellites increases with the number of satellites. As the number increases, the coverage for a given time increases, and hence the sampling interval at a given point decreases. In the GPM era, eight sun-synchronous polar-orbiting satellites enable global observation of precipitation every 3 hours. In the GPM era, one primary satellite and eight constellation satellites will produce 3-hour global precipitation maps that will be delivered to users in near real time.

Constellation of several satellites developed by each international partner (space agency) will carry passive microwave radiometers and/or microwave sounders and be in operation around 2014-2018. The DPR and GMI instruments on board the core satellite will serve as a 'calibrator' for data obtained by constellation satellites.

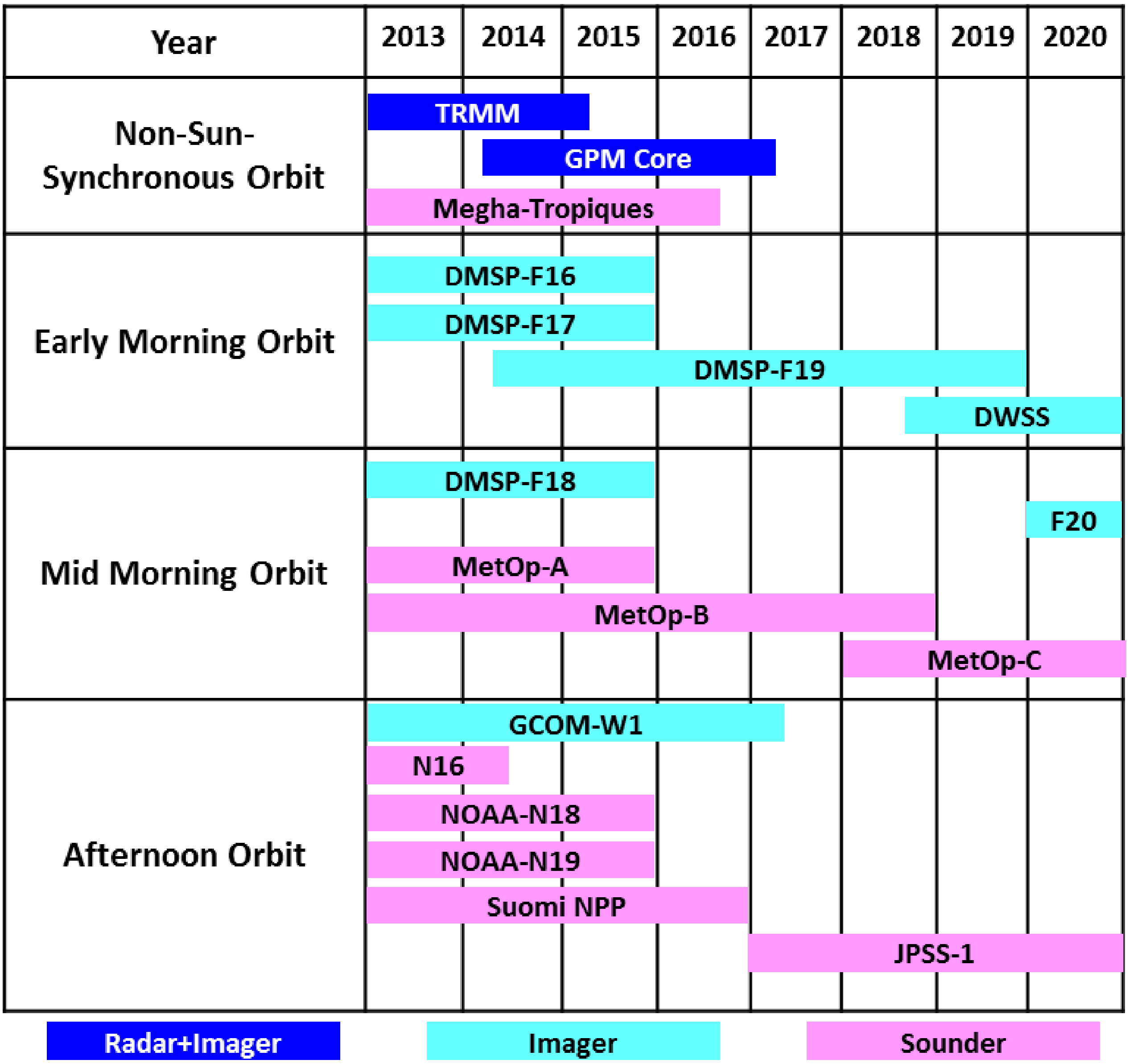

Figure 4 Worldwide Missions for Satellite Precipitation Observation (2013-2020) as of April 2015.

APPENDIX 3

OVERVIEW OF
THE EARTH CLOUD, AEROSOL AND RADIATION EXPLORER (EarthCARE) MISSION

1. Introduction

1.1 Cloud and Climate Change

Since the last report of IPCC (Third Report), the level of scientific understandings regarding the effect of aerosols and clouds, show a good progress. From the most recent report (Fourth Assessment Report; FAR), carbon dioxide is said to be the largest factor to the influence of the global warming. However, the effect of carbon dioxide to the global warming is considered to have been evaluated with a good accuracy. On the other hand, the radiative forcing of clouds and aerosols still remains as the dominant uncertainty in the prediction of the climate change in the future. It is reported that -0.5 W/m^2 for aerosol direct effect and -0.7 W/m^2 for cloud albedo effect, -1.2 W/m^2 as total aerosol, are counted for radiative forcing relating with aerosol/cloud. The figure is large enough comparing with the total anthropogenic radiative forcing; +1.6 W/m^2. We have to make a special attention to the fact that the uncertainty of the cloud albedo effect, i.e. interactions between aerosol and cloud, is very large; 2 W/m^2. This leads, without the correct understanding of the interaction between aerosol and cloud, climate change to remain uncertainties to predict future status with sufficient accuracy.
Furthermore, FAR suggests that the cloud life cycle process should be examined not just for cloud forming but also for the precipitation process or cloud termination process, which will affect global radiation budget through latent heat release and changing the radiative characteristics of the ground surface by such as snowing (IPCC, 2007).

1.2 EarthCARE mission and instruments

Japanese Aerospace Exploration Agency (JAXA), National Institute of Information and Communications Technology (NICT) and European Space Agency (ESA) are going to materialize a project named “Earth Cloud, Aerosol and Radiation Mission; EarthCARE”. EarthCARE is a challenging mission toward to solve the issues noted in the previous section. The observation scope of the EarthCARE is to observe globally such processes; the aerosol distribution, cloud forming with aerosol interaction and beginning of precipitation. To materialize such observation, four instruments were chosen, with their respective needs, to load on EarthCARE; LIDAR (light detection and ranging) and Doppler Radar for the aerosol/cloud profile observation, multi spectral imager (MSI) for aerosol/cloud lateral distribution observation and broadband radiometer (BBR) for Earth radiative flux observation. The observations by these instruments guarantee their synchronism and their uniformity in the observation region. In other word, more accurate synergy observations are preserved, by minimizing the differences in the condition of the observations between the instruments, resulted from such as the differences in the timing of the observation. The relationship between target geophysical parameters and instruments is shown in figure 1. The final goal of the mission is to reconstruct aerosol cloud structure with their physical characteristics with the accuracy of 10 W/m2 as radiative flux at top of atmosphere (ESA,2004, Gelsthorpe et.al., 2008).

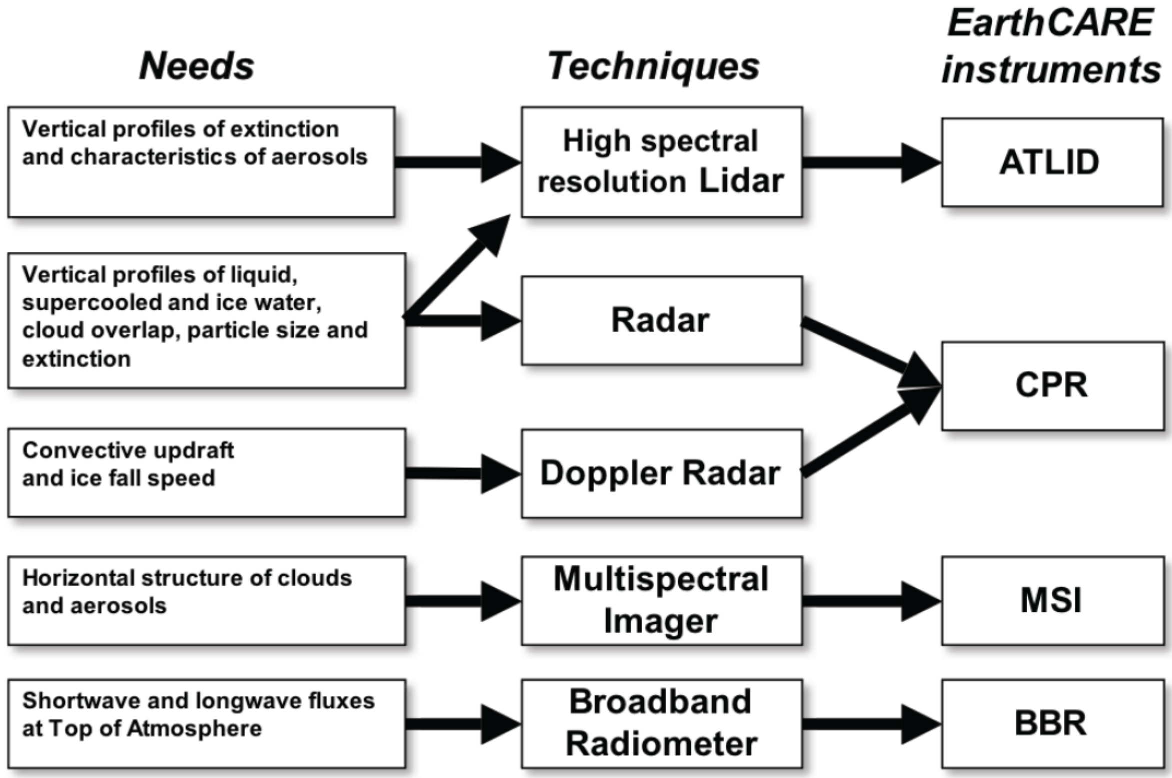

Figure 1 Relationship between target geophysical parameters and instruments

The outlook of EarthCARE satellite and CPR are shown in figure 2. A sun synchronous orbit was chosen as the observational orbit to cover all region of the Earth. Local time at equator of the orbit is 13:45 to 14:00 with consideration of cloud processes being active in the afternoon.

To get the accurate aerosol/cloud observation data, several unique points are implemented for instrumentation. The LIDAR is an Ultra Violet range single wavelength High Spectral Resolution LIDAR. The wavelength, 355 nm, has well sensitivity for the small aerosol particles that are missed by Radar, and make high transmit power possible for its eye safe character. It is possible for the LIDAR signals to be strongly attenuated when they meet dense regions composed by large particles such as clouds. High spectral resolution enables to receive Mie and Rayleigh scattering signals independently. In this way, the optical properties of aerosols can be retrieved directly, without an assumption of liar ratio. Through its polarization measurement, the depolarization ratio can be calculated to estimate the nonsphericity of the observed particle. Doppler W-band Radar penetrates thick cloud layers. Doppler measurement function distinguishes cumulus / convective cloud types and its particle status inside of cloud layer. Using Doppler value, we precisely know kinds of cloud particles. The detailed description of the Doppler Radar is noted in Section 2.1. The MSI has 7 channels with their central wavelengths to be 0.67, 0.865, 1.65, 2.21, 8.8, 10.8 and 12.0 μm, respectively. These channels will be used with split window method to get optical depth and effective radius of cloud and aerosols. Thermal infrared channel can be used to retrieve the cloud top height. The ground resolution of MSI is 500 m^2 and the swath width is 150 km. BBR design is a heritage of past Earth Radiation Mission, such as ERBE or CERES. BBR has two channels; one for the observing shortwave (0.25 ~ 4μm) and the other for longwave (4 ~ 50μm). Three angle radiometer will be used for flux determination considering its angular distribution. The effect of cloud forcing by the reflection of sunlight as well as by its emittance of longwave radiation are expected to be evaluated from the BBR observation. General characteristics for all four instruments are shown in Table 1.

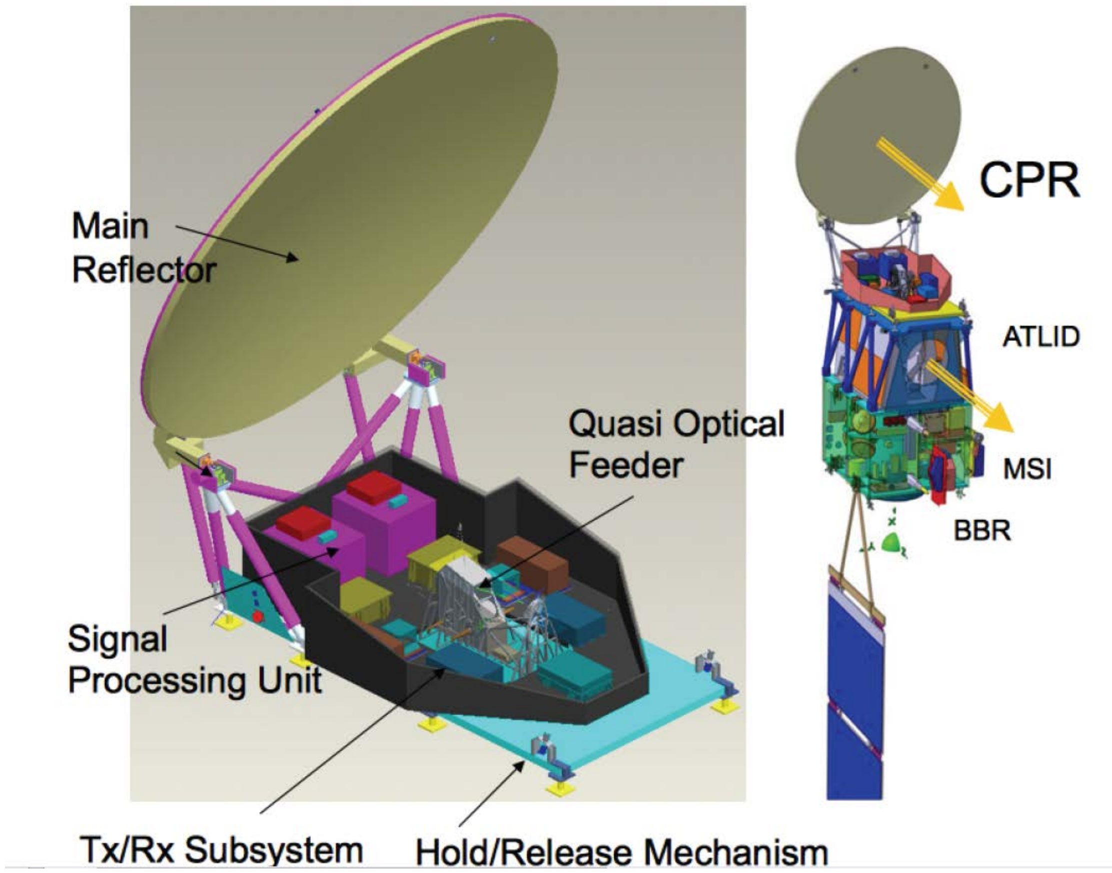

Figure 2. Outlook of CPR and EarthCARE satellite

Table 1 General characteristic of instruments

Instrument	Description
CPR	94 GHz Doppler Radar (see Table 2.)
ATLID	355 nm Hyper Spectral Resolution Lidar with three channels (Mie co-polar, Rayleigh, Mie cross-polar)
MSI	Push broom imager Resolution 500m, swath 150 km Seven channels (0.67, 0.865, 1.65, 2.21, 8.8, 10.8, 12.0 micron)
BBR	Three views radiometer Angle: Nadir, +- 55 deg Two channels; 0.2–4, 4–50 micron

4. Doppler Cloud profiling RADAR

The new space borne radar; Cloud Profiling Radar (CPR) is going to be developed in the cooperation between JAXA and NICT. From CPR observational requirements, we identified following design requirements. First point is the high sensitivity. This requirement is divided into large antenna size requirement, low noise figure of receiver requirement and high power of transmitter requirement. Second point is the Doppler capability. To materialize this function with satisfactory accuracy, large diameter of antenna with precise surface figure and high pulse repetition frequency (PRF) are required. To keep accuracy especially at boundary layer region, several other fine characteristics, such as side lobe characteristics of antenna, cross polarization characteristics and so on, are also required for CPR design.

As the result of design, we chose pulse pair scheme for Doppler measurement. In addition, the diameter of antenna was set as 2.5 m considering the limited diameter of launcher fairing. For transmitter, we employed improved Extended Interaction Klystron (EIK), of which original model is already employed for CloudSAT mission by NASA (Stephens et.al., 2002). The transmit power is 1.5 kW at end of three year mission. For PRF design, CPR has variable control capability of PRF with satellite altitude information. This is for maximizing frequency to keep good coherency between radar pulses, also good sensitivity by having much integration. Outlook of CPR is shown in Figure 2 and major specification of CPR is shown in Table 2.

However, the PRF is a factor of trade off between observational heights. Considering the natural cloud height distribution, the planned operation of CPR is to change observational height with latitude. As natural cloud height distribution, for low latitude region, the cloud height is rather high; in contrast, the polar region cloud height is rather low. The image of CPR operation is shown in Figure 3.

Table 2. General Specifications of CPR

Item	Specification
Radar Type	94 GHz Doppler Radar
Center frequency	94.05 GHz
Pulse width	3.3 micro second (equivalent to 500m vertical resolution)
Beam width	0.095 deg
Polarization	Circular
Transmit power	> 1.5 KW (Klystron spec.)
Height range	-0.5 ~ 20 km
Resolution	500 m (100 m sample); Vertical 500 m integration; Horizontal
Sensitivity*	-35 ~ +21 dBZ
Radiometric accuracy*	< 2.7 dB
Doppler range*	- 10 ~ +10 m/s
Doppler accuracy*	< 1 m/s
Pulse repetition frequency	Variable; 6100 ~ 7500 Hz
Pointing accuracy	< 0.015 degree

; at 10 km integration and 387 km orbit height

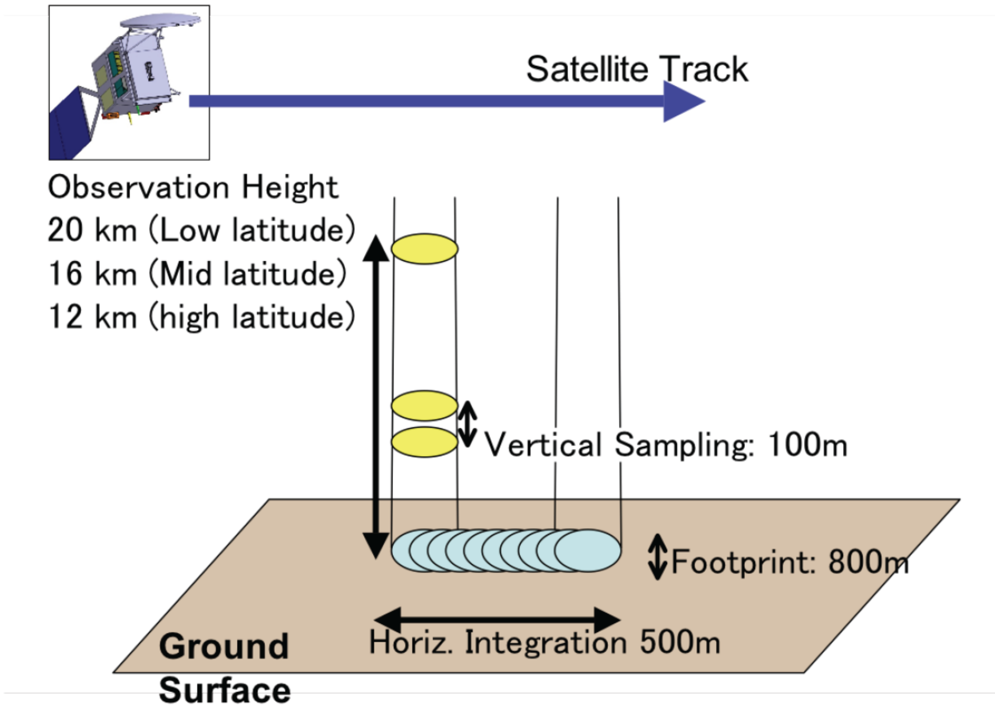

Figure 3. CPR Operation Image

5. Operation Planning

EarthCARE is planned to be launched in JFY2015. The calibrated engineering parameters (Level 1 data) and the retrieved physical parameters (Level 2 data) by all four sensors on EarthCARE will be stored and distributed from both JAXA and ESA. Data are planned to be used by research institutes and agencies in order to improve the accuracies of numerical weather/climate models. The data are also opened to researchers (after appropriate procedures), and are used in the analysis of radiation/aerosol/cloud/precipitation process.

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APPENDIX 4

OVERVIEW OF THE ADVANCED LAND OBSERVING SATELLITE-2 (ALOS-2) MISSION

1. Introduction

The Advanced Land Observing Satellite-2 (ALOS-2) is succeeding to the radar mission of ALOS which had contributed to cartography, regional observation, disaster monitoring, and resources surveys.

ALOS-2 is equipped with a SAR antenna just under its body and with two solar array paddles at both sides, as shown in Figure 1. The observation data is transmitted directly to a ground station via X-band or through inter-satellite communication via Ka-band. The transmission speed is 800 Mbps maximum for X-band and 278 Mbps for Ka-band, respectively. Table 1 shows system specifications of ALOS-2. The local sun time of it orbit is at noon in order to complement other SAR satellites which are in dawn-dusk orbits.

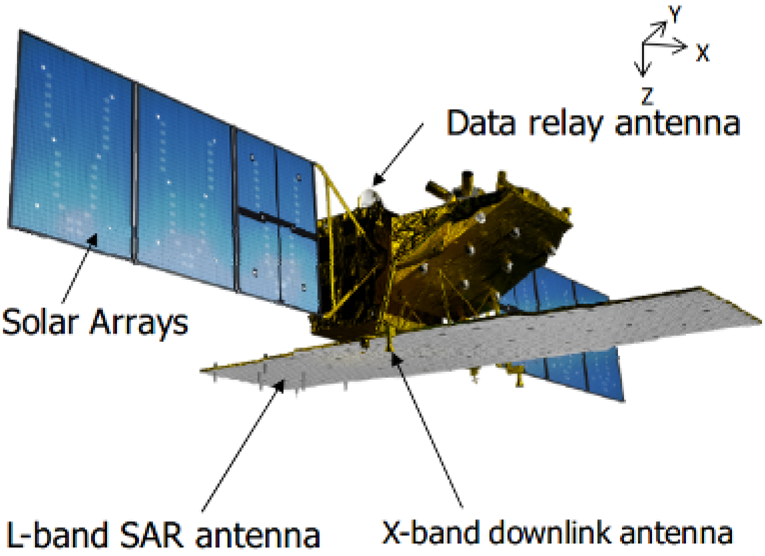


Fig. 1 ALOS-2 in-orbit configuration

Table 1 ALOS-2 specification

Observation mode	Stripmap: 3 to 10 m resolution, 50 to 70 km swath ScanSAR: 100 m/60 m resolution, 350 km/490 km swath Spotlight: 1×3m resolution, 25 km swath
Orbit	Sun-synchronous sub-recurrent orbit Altitude: 628 km Local sun time : 12:00 +/- 15 min Revisit: 14 days Orbit control: < +/-500 m
Launch	May 24, 2014 (JST), H-IIA launch vehicle
Life time	5 years (target: 7 years)
Satellite mass	Approx. 2 tons
Downlink	X-band: 800 Mbps (16QAM), 400/200 Mbps (QPSK) Ka-band: 278 Mbps (QPSK)

2. PALSAR-2 Characteristic

ALOS-2 carries the state-of-the-art L-band Synthetic Aperture Radar (SAR) called PALSAR-2. PALSAR-2 has a Spotlight mode (1×3m resolution in Az×Rg), a Stripmap mode (3 to 10 m resolution) and a ScanSAR mode. The Spotlight mode and a high resolution mode will allow providing users with more detailed data than ALOS/PALSAR. The ScanSAR mode will allow us to acquire a 350 to 490 km width (depends on number of scans) of SAR images at the expense of spatial resolution. The observation frequency of ALOS-2 will also be improved by greatly expanding the observable areas (2,320km). Right-and-left looking function by satellite maneuvering and electric beam steering using active phased array antenna establish the incidence angles from 8 to 70 degrees on both side of the satellite.

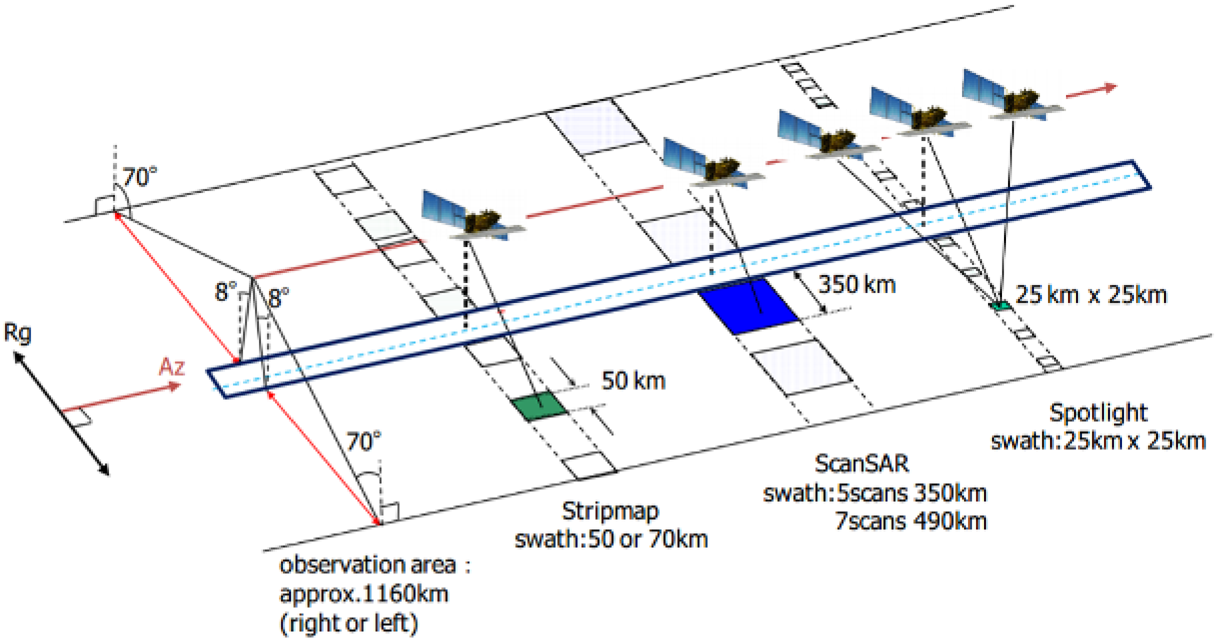


Fig. 2 PALSAR-2 observation modes

Table 2 PALSAR-2 specification

Observation mode		Spotlight	Stripmap			ScanSAR
			Ultra-Fine	High-Sensitive	Fine	
Incidence angle		8 to 70 degrees				
Band width		84 MHz	84 MHz	42 MHz	28 MHz	14 MHz/28 MHz*
Ground resolution		3 m x 1 m (Rg x Az)	3 m	6 m	10 m	100 m (60 m)
Swath		25 km	50 km	50 km	70 km	350 km (490 km)
Polarization		Single	Single/Dual	Single/Dual/ Full/Compact	Single/Dual/ Full/Compact	Single/Dual
NESZ		-24 dB	-24 dB	-28 dB	-26 dB	-26 dB/-23 dB
S/A	Rg	25 dB	25 dB	23 dB	25 dB	25 dB (20 dB)
	Az	20 dB	25 dB	20 dB	23 dB	20 dB

The parameters specified at 37degrees incidence angle above the equator.
* 28 MHz bandwidth in ScanSAR mode is used for only 350 km swath

PALSAR-2 is composed of two subsystems; Antenna subsystem (ANT) and Electric Unit (ELU). ANT is an active phased array antenna, which steers a beam both in elevation and azimuth direction (plus-minus 30 degrees in elevation and plus-minus 3.5 degrees in azimuth). Figure 3 shows the antenna configuration of PALSAR-2. The size of ANT is 10 m in azimuth and 3 m in elevation, and is composed of five electrical panels, which have 180 Transmit-Receive-Modules (TRMs) in total. The Spotlight mode and Ultra-Fine mode use the three of five panels to satisfy resolution requirement and the other modes use all panels. The transmitted power is 3950 W and 6120 W respectively.

Figure 4 shows the system diagram of PALSAR-2. Key components of the Electric Unit (ELU) are Exciter (EX), Transmitter (TX), Receiver (RX), Digital Processor (DP), and System controller (SC). As for RF signal, EX generates pulses, selects two chirp signals (up or down and phase modulation) with a selected center frequency either 1257.5, 1236.5 or 1278.5 MHz in order to avoid interference to Radio Navigation Satellite Services which use L-band, and stretches the signal to a selected bandwidth either 84 MHz, 42 MHz, 28 MHz or 14 MHz. Received radar echo signals are compressed by BAQ or DS-BAQ algorithm. Compression mode is selected from 4 bit, 2 bit, or no compression.

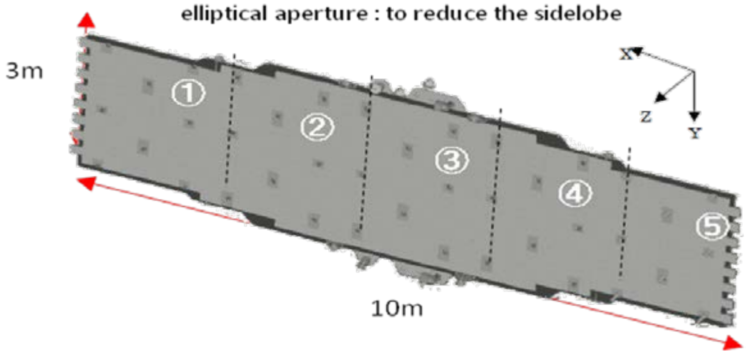


Fig. 3 PALSAR-2 antenna configuration

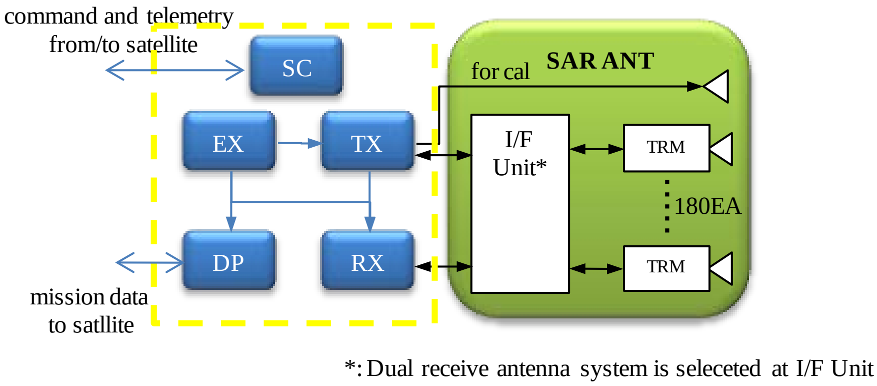


Fig. 4 PALSAR-2 system diagram

3. ALOS-2 Data Products

3.1 Definition of ALOS-2 Data Products

Two categories of data products are defined - level 1 product and higher level products.

3.1.1 Level 1

Level 1 is radiometrically and geometrically calibrated data and is a standard JAXA product for ALOS-2 users.

3.1.2 Higher-level data product

Products above level 2 are higher-level data products. Higher-level data products are made more sophisticated by processing with digital elevation models. This is provided by JAXA's EORC as soon as ready.

3.2 Standard Data Products

Table 3 PALSAR Standard data products

Level	Definition	Note
1.1	Range and azimuth compressed complex data on slant range. Full resolution	Beam modes: Full resolution mode, Low data rate mode, Polarimetric mode SLC: Single Look Complex Used for interferometry
1.5	Multi-look processed image projected to map coordinates. Option G: Systematically Geo-coded (No option: Geo-referenced)	Map projection Resampling Pixel spacing
2.1	Ortho-rectified and slope corrected products	Map projection Resampling Pixel spacing

4 ALOS-2 Operation Concept and Observation Strategy

ALOS-2 is operated based on the Basic Observation Scenario-2 (BOS-2) that is optimized as the background mission while the emergency observation is the highly prioterized operation for the disaster mitigations. The BOS-2 is open to the public through ALOS-2 i.e. *http://www.eorc.jaxa.jp/ALOS/en/top/obs_top.htm*

The BOS-2 is designed to achieve the Earth observation using the several modes of the PALSAR-2, i.e. high resolution strip mode (84 MHz-singe polarization), Dual polarization mode (42 MHz-Dual Polarization), Quad-mode (42 MHz-Full polarization), Dual Strip (28 MHz), and ScanSAR (14 MHz-Dual-350 Km /490 Km swath) for observing the solid earth (deformation study), biosperic study (forest monitoring, carbon estimation) and Cryospheric study (sea-ice, polarer monitoring), and map generation.

APPENDIX 5

EARTH OBSERVATION PRIORITY RESEARCH

Contents

1. About Earth Observation Priority Research

'Earth Observation Priority Research' aims to solve social probrem, by using complex satellite data such as 'Himawari-8' which satellite isn't developed by JAXA, and using modeling technique, assimilate technique.

(1) Fusion satellite data and earth environment modeling

Earth observation satellite contributed to monitor earth environment and disaster, in the future, in addition to this, we need to proceed high-level application by using global satellite data and modeling. To forecast the process of the earth, it is necessary a lot of satellite data and complex model and simulation.

(2) Earth observation as both earth science and social application

One earth observation satellite contributes two aspects, earth science and social application. So we don't separate these aspects, rather, our earth observation priority research aims two objectives, social application and earth science development.

(2) List of Earth Observation Priority Research

The table below shows themes and Satellites to be used for earth observation priority research. Yellow cells mean EORC managed study.

Research field \ Satellite		ALOS-2	GPM/ TRMM	Earth CARE	GCOM	GOSAT	Hima wari
Application to Disaster Prevention		○					
Ocean Monitoring	Ship Monitoring	○			○		
	Ocean Environmental Monitoring		○		○		○
Water Cycle and Water Resource Management			○		○		○
Atmospheric Environmental Monitoring				○	○	○	○
Infrastructure Displacement Monitoring		○					
Climate System and Radiation Process			○	○	○	○	○
Ecosystem		○	○		○	○	○
Agriculture		○	○		○		○
Public Health		○	○		○		○

2. Overview of each satellite cross cutting research

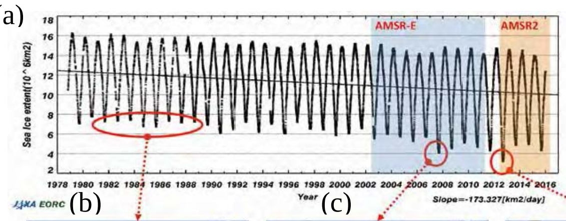
Following page describes overview of earth observation priority research.

2.1. Ocean Environmental Monitoring

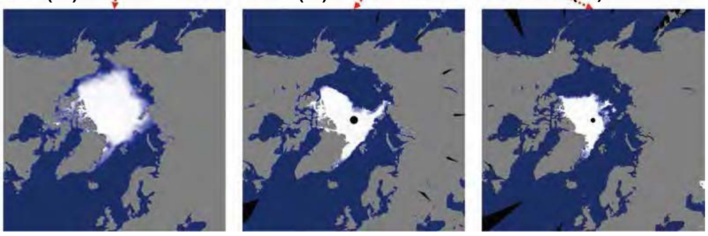
The changes in the ocean environments affect not only everyday weather and changes to fishing grounds, but also large-scale atmospheric circulation, climate systems and marine ecosystems. EORC develops and produces data on ocean parameters, such as sea surface temperature, sea ice, chlorophyll-a concentration (phytoplankton's photosynthetic pigment) and photo synthetically active radiation (sunlight effective for the photosynthesis of plants), based on various observation data sets. Then, EORC provides the data and images to researchers and general users. We also produce continuous ocean environmental data sets, which without missing values, include parameters that cannot be observed directly from satellites, in coordination with ocean models The goal of the research is to contribute to the both climate research and operational application, such as utilization in fisheries.

■ Long-Term Global All-weather Observation using Passive Microwave Imagers - Arctic Sea Ice Monitoring

(a)

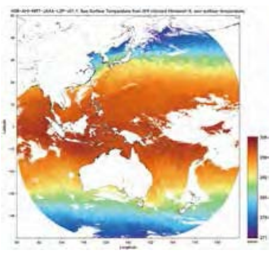


Sea Ice Extent Changes in the Arctic Sea using Passive Microwave Imagers (1978/11 - 2016/1)

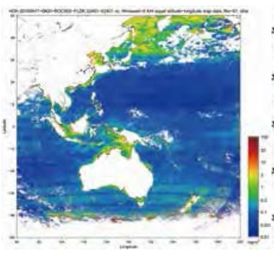


Passive microwave imagers can observe sea ice distribution or sea surface temperature through clouds, and have provided essential information for understanding the influence of climate changes since late 1978 by continuous observation with multi-sensor.Based on long-term and continuous observation of the Arctic Sea Ice Extent from Nov. 1978 to Jan. 2016 (a), the AMSR-E on the Earth observation satellite "Aqua" captured the second smallest extent (c) in the record in September 2007 and the AMSR2 on the Global Change Observation Mission (GCOM-W) "SHIZUKU" captured the smallest sea ice extent (d) in the record of satellite observation in September 2012.

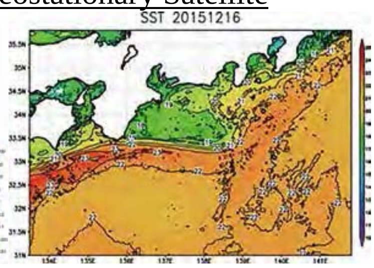
■ High-Frequent Observation using a Geostationary Satellite



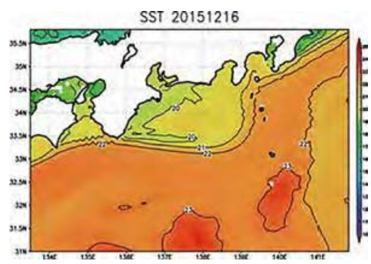
(e) Observation of Sea Surface Temperature by "Himawari-8"



(f) Observation of Chlorophyll-a by "Himawari-8"



(g) Data Assimilation Result of Sea Surface Temperature Observed by "Himawari-8" into the Ocean Model over the Southern Coast of Japan with a 3km resolution (December 16, 2015)



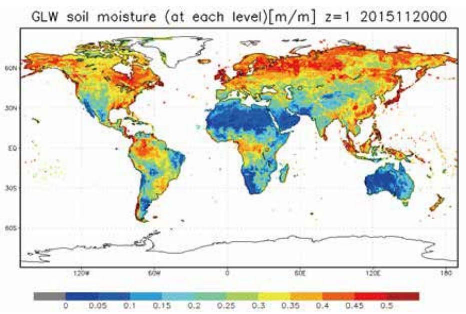
(h) Data Assimilation Result of Sea Surface Temperature Observed by the MODIS into the Ocean Model over the Southern Coast of Japan with a 11km resolution (December 16, 2015)

The geostationary meteorological satellite "Himawari-8", which started its operation in September 2015, has 0.5 ~ 2-km spatial resolution and performs full-disk observations every 10 minutes. JAXA produces data sets on high-frequent sea surface temperature (e) and chlorophyll-a concentrations (f). Further, these data sets are assimilated into high-resolution ocean models (g, h) in cooperation with collaborating institutes. Through these research activities, EORC is building new ocean environmental data sets where satellite observation is integrated with numerical models.

2.2. Water Cycle and Water Resource Management

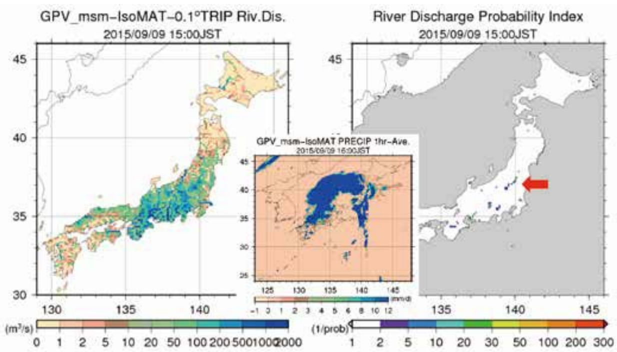
Circumstances are now occurring that affect human activity globally: Frequently occurring atural disasters such as floods and droughts currently due to the climate changes affect not only local areas, but are global in scale. EORC monitors the global water cycle and combines satellite observation data and land numerical modeling to estimate physical amounts (river discharge and soil moisture, etc.), which will be key factors for solving issues such as water and food shortages and other related disasters. They provide hazard indexes as easily usable information (water cycle data set). They also promote analysis with the data integrated into ecosystem data, etc., to produce measures to satisfy the worlds demand for food and water for ten billion people.

■ Constructing Global 0.5-degree Grid Resolution Land Simulation System - Soil Moisture Content



The system that used to have a 1-degree (about 100km) grid has now been changed to a much higher resolution of 0.5-degree (about 50km) grid for the land model, and a 0.25-degree (about 25km) grid for river models. In order to obtain the flood disaster level for a mid-sized river, EORC makes an estimation of the river discharge and flooded area rate.

■ Japan Area High-Resolution Land Simulation System Examination
- Discharge Estimation for Kinugawa River Overflow at 3 O'clock on September 9, 2015



A land model that is able to estimate local scale flood disaster (not achieved in any other place in the world) has been created by improving the spatial resolution from 10km to a much more accurate 1km. In addition, EORC provides water cycle data sets combined with satellite data and a hazard index to gather flood disaster data along domestic class-A rivers.

Provided by Mr. Yoshimura, Associate Professor, the University of Tokyo, Simulation Result in Today's Japan (10km Grid)

■ Development and Release of Global Satellite Mapping of Precipitation (GSMaP)'s latest version (GSMaP_NOW)

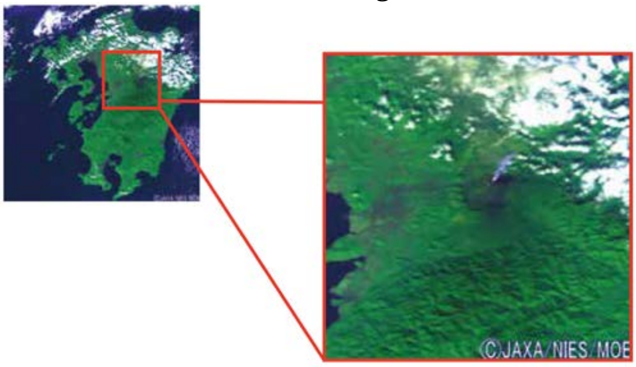
http://sharaku.eorc.jaxa.jp/GSMaP_NOW/

The precipitation distribution map has been prepared using only microwave radiation scale data (mainly the GMI sensor, the AMSR2 sensor over the area around Japan, and the AMSU direct received data) available within 30 minutes after observation within the observation range of the Geostationary Meteorological Satellite "Himawari". Furthermore, EORC prepares "real time" precipitation distribution maps on the hour and 30 minutes of every hour. This is to respond to requests for a reduced distribution time by many users, by extrapolating the map data for 30 minutes in the future, using the cloud motion vector calculated from the Geostationary Meteorological Satellite.

2.3. Atmospheric Environmental Monitoring

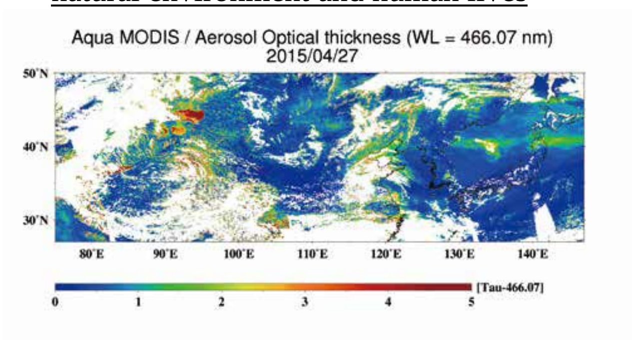
Air pollutants such as desert dust and PM2.5, volcanic ash and forest fire, greatly influence our living environment. These atmospheric fine particles (called “aerosols”) cause poor visibility, damage to cars, houses and agricultural products, and health hazard. Using various satellite data over the world, EORC estimates aerosol optical thickness (atmospheric turbidity index) and the Ångström exponent (aerosol particle size index) and provides the data products and images to researchers and general users. We aim to build, in coordination with external organizations, a system that predicts when, from where, to where and what concentration the aerosol comes by air, by building a data assimilation system where satellite data is incorporated into the aerosol transport model. In Atmospheric Environmental Monitoring, we also develop fire detection product and cloud product that will be important for the aerosol source information and for detecting cloud evolution.

■ <u>Aerosol Observation using Satellites</u>



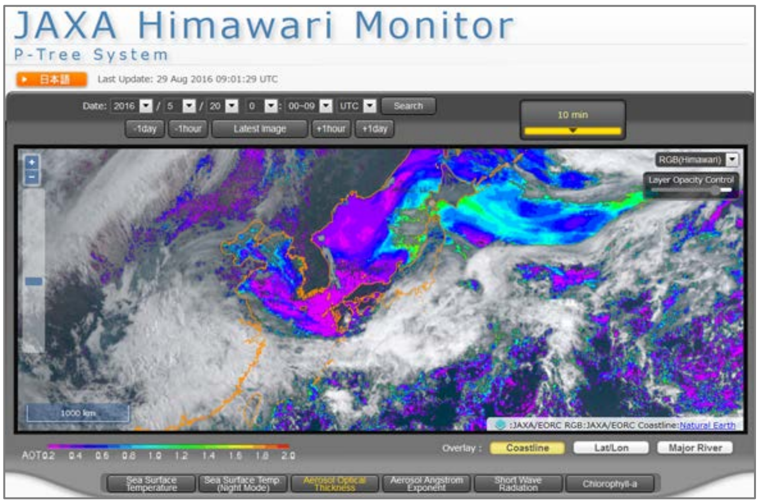
The above images show the eruption of Asosan Mountain observed by TANSO-CAI sensor onboard the Greenhouse Gases Observation Satellite (GOSAT) “IBUKI” on November 17, 2015

■ <u>Atmospheric Particle Aerosol affecting natural environment and human lives</u>



Aerosol optical thickness observed using the MODIS sensor loaded on the Earth Observation Satellite “Aqua” on April 27, 2015 Smoke from forest fires in China passing over the Northeast Japan is clearly seen.

■ <u>Product Distribution from JAXA Himawari Monitor</u>

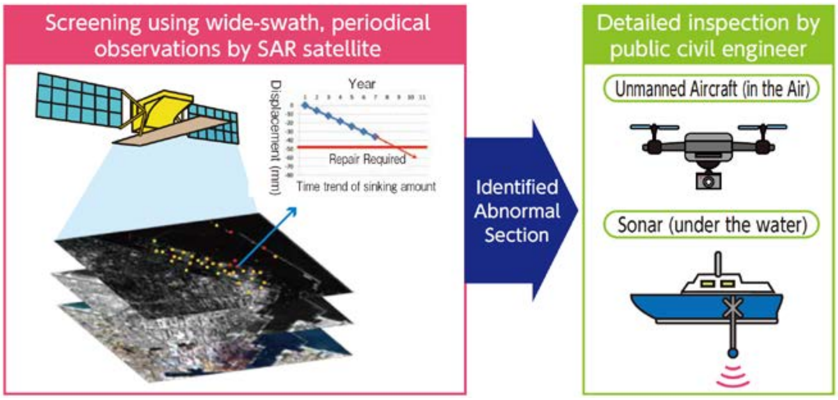


We develop the product distribution system that that routinely process and disserminate the products developed in the Atmospherc Environmental group from JAXA Himawari Monitor (http://www.eorc.jaxa.jp/ptree/index.html)

2.4. Infrastructure Displacement Monitoring

EORC detects civil engineering infrastructure displacement, utilizing characteristics of satellite observation that can periodically make wide observations using the observation data from the L-band Synthetic Aperture Radar (PALSAR-2) loaded on the Advanced Land Observing Satellite “DAICHI” (ALOS) and “DAICHI 2” (ALOS-2). Based on the results, EORC research contributes to better and much more effective civil engineering infrastructure management performed by national or local governments (Fig. a). JAXA develops and validates the variation in the amount estimation measurements difficult to visualize, in addition to the development of the Permanent Scatters Interferometry Synthetic Aperture Radar (PSInSAR) algorithm, that is the basis of their research. They have confirmed deformities in sections of the harbor facilities by analysis (Fig b) and measurement of sinking river dikes (Fig c).

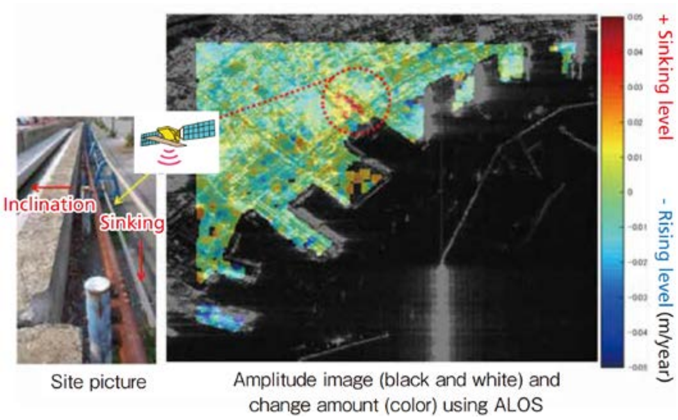
■ <u>Infrastructure Displacement Monitoring</u>



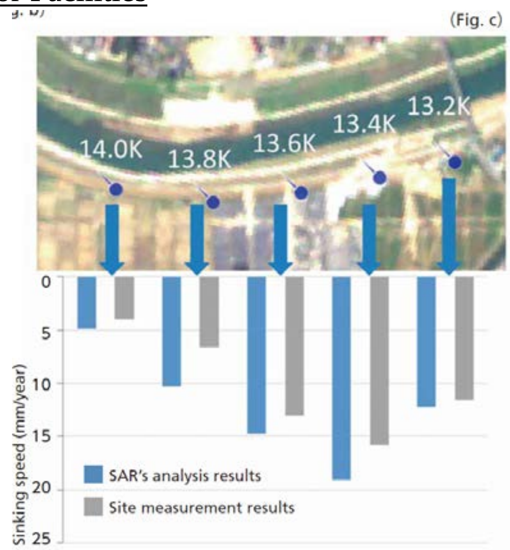
（Fig. a）
Periodical wide-swath observation using SAR satellites enables us to locate the condition of the changed sections (red circle sections) requiring inspection and narrows down the sections for which detailed inspection is to be performed.

* SAR satellites: Advanced Land Observing Satellite “DAICHI” (ALOS) and “DAICHI 2” (ALOS-2)

■ <u>Understanding of the Changing Conditions of the Harbor Facilities</u>



The red circle shows the area with larger minimal sectional change. This area agrees with the one pointed out by the facility manager that would need to be changed.



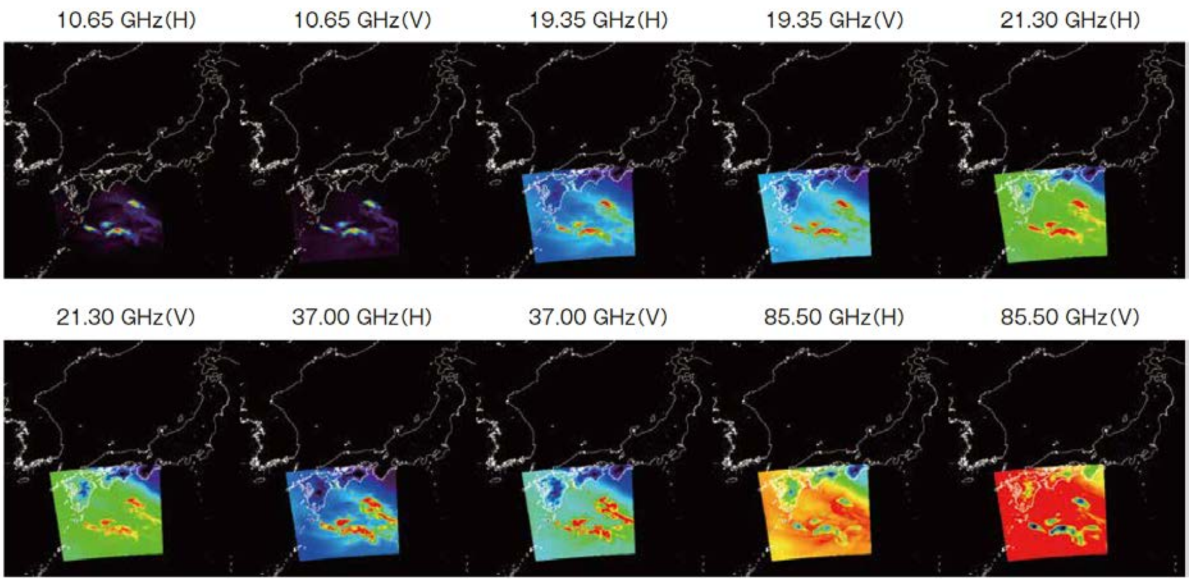
■ <u>Understanding of the Changing Conditions of River Banks</u>

The sinking tendency information is obtained periodically with the Interferometric SAR (InSAR) Time Series Analysis using SAR satellite. Providing such information to the manager is useful for decision-making for preparing a repair plan and inspection plan, etc. The result of the InSAR Time Series Analysis has as much accuracy as the result of the measurement data at the site. With this method, EORC performs research and development to obtain more complete data on the sinking tendency.

2.5. Climate System and Radiation Process

The software (for Radiative Transfer Code and Satellite Data Simulator) required for the higher-level earth observation satellites has been developed for the basis of researches. Also, research on how to use this software effectively is being conducted. For example, jointly with the University of Tokyo, research will be done with the world latest Global Cloud-resolving Numerical Atmospheric Model (NICAM). This will simulate the Earth's atmosphere, expressing cloud and precipitation process very realistically, and the NICAM will be assessed using the data collected from two or more satellites. Also, research is being done to contribute to the enhancement of weather forecast accuracy by introducing cloud and precipitation data from satellites into numerical weather prediction These are joint-works with the Meteorological Research Institute in the Japan Meteorological Agency, and RIKEN.

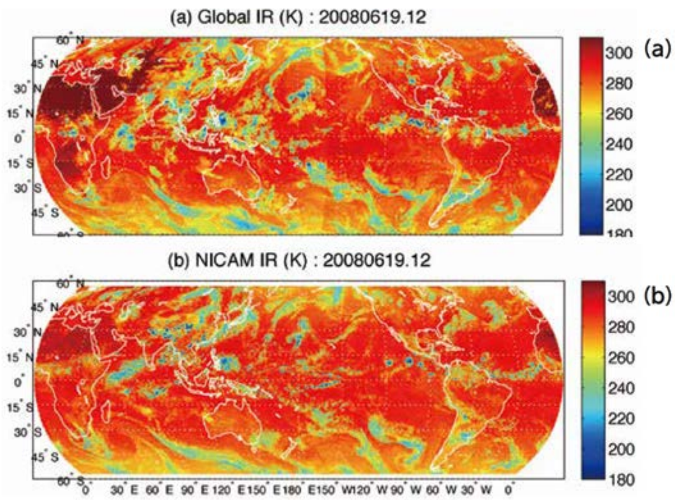
■ Example of the Results of Passive Microwave Radiometer Simulation around Japan



Simulation Results of the Tropical Rainfall Measuring Mission's microwave observation system (TRMM Microwave Imager: TMI) observations around Japan using the satellite data simulator (Joint-Simulator): The atmospheric data obtained using the JMA Non-Hydrostatic Model provided by the Me teorological Research Institute, Japan Meteorological Agency, has been employed for the calculation. Difference in brightness in the above simulation results clearly shows the temperature corresponding to the TMI's observed frequencies and polarized waves.

■ Comparison between Geostationary Meteorological Satellite (GMS) data and Simulation Data (Hashino et al. 2013)

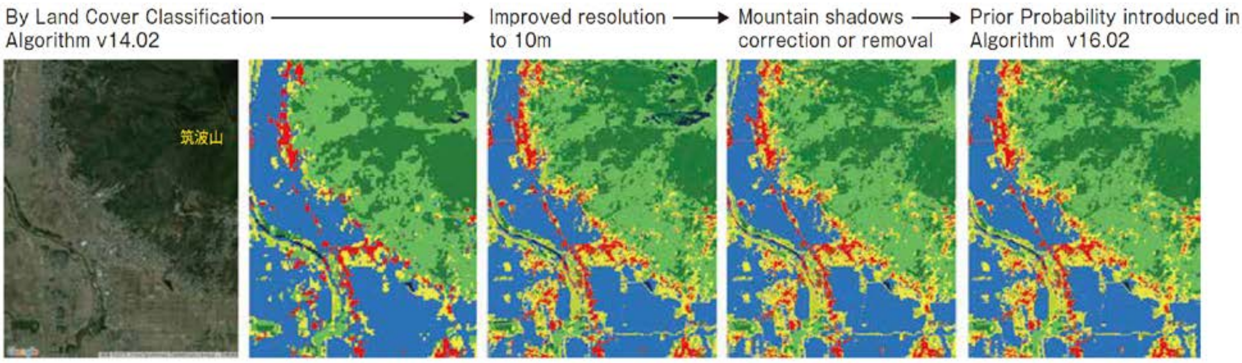
(a) Geostationary Meteorological Satellite Data (IR 10.8 μm)
(b) Synthetic satellite data created based on the Global Cloud-resolving Atmospheric Model (NICAM) 3.5km resolution simulation data with satellite data simulator (Joint-Simulator) applied Comparing (a) to (b) clarifies that NICAM reproduces the horizontal cloud distribution successfully.



2.6. Ecosystems

Recently, the land surface changes have been accelerated due to forest destruction, urbanization and disasters, etc. A land-use and land-cover classification (LULC) map is required so that changing land surfaces time to time can be caught up on. EORC develops satellite high-order calibrated products required for the above, the reference database for classification and validation, and development of the classification algorithms makes great efforts to enhance the quality of these products through the partnership with universities and research organizations.EORC has created comprehensive and high quality LULC map where JAXA's past, current and future satellite data items are effectively used and various sensors such as optical, microwave, active and passive, are combined.

■ Development of High Resolution Land Cover Map

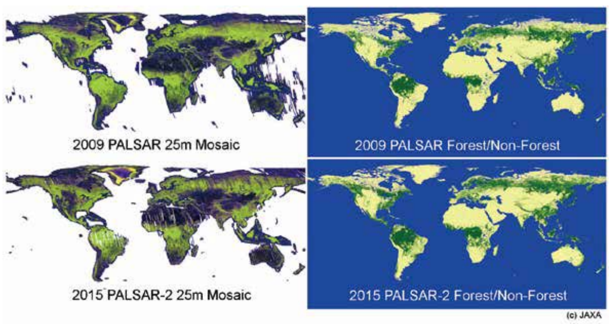


EORC provides a 10m resolution land-use and land-cover map by using a high-order calibrated product mainly with the AVNIR-2 sensor aboard the Advanced Land Observing Satellite (ALOS) "DAICHI". This map is effectively used for the evaluation and assessment of agricultural land changes, etc.

■ Maintenance of Land Cover Classification Reference Database
(Site-based dataset for Assessment of Changing Landcover by JAXA: SACLAJ)

EORC constructs a data base where on-ground information survey data (site photos, etc.) provided from web interfaces by researchers and students, and satellite images, aerial photographs and monitoring data are integrated to monitor long-term land surface changes.

■ Global 25m Resolution PALSAR-2/PALSAR Mosaic & Forest/Non-Forest(FNF) Map

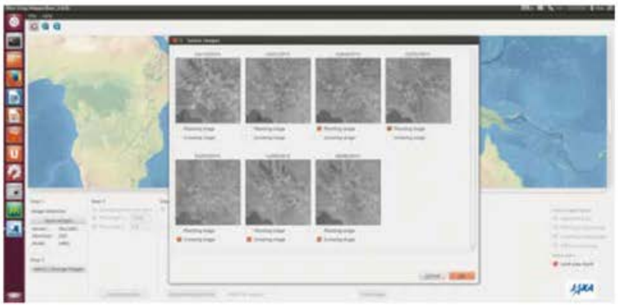


This data set has been prepared with high-accuracy high-speed bulk processing analysis technology developed by EORC, applied to global data from the L-band Synthetic Aperture Radars (PALSAR and PALSAR-2) loaded on the Advanced Land Observing Satellites "DAICHI" (ALOS) and "DAICHI 2" (ALOS-2). It has been confirmed that the classification accuracy of Forest/Non-Forest (FNF) maps is 84% or more of the reference data site photographs and high-resolution optic satellite images after comparison.

2.7. Agriculture

Japan depends on imports for most of its food. When we turn our eyes to the world, 800 million people, 10% of the world population, lack adequate nourishment. Concerning issue, we hope to help create societies where the governments of various nations of the world, international organizations and private enterprises can make decisions effectively and efficiently for crop production, import and export, and food assistance. This can be based on scientific and objectively measured crop growing conditions and yield prediction data using earth observations. EORC works hard on research and development to continuously survey and make forecasts about crop yields. This includes where crops are produced, growing conditions, when and how much is harvested etc., in cooperation with research organizations and government agencies in and out of Japan.

■ Estimation of Paddy Rice Planted Area using Synthetic Aperture Radar (ALOS-2)
- Development of Software "INAHOR"



Selection of the Synthetic Aperture Radar to be used

Estimation Results for the Paddy Rice Planted Area (blue section)

Software "INAHOR" (International Asian Harvest mOnitoring system for Rice) has been developed, which estimates the area of the paddy rice to be planted. This uses data from the L-Band Synthetic Aperture Radar (PALSAR-2) on the Advanced Land Observation Satellites "DAICHI 2" (ALOS-2) operated for two or more time periods. In South East Asia, in particular in the rainy season when paddy rice is planted, the subject area is often covered with heavy cloud. However, the synthetic aperture radar can monitor rice conditions regardless of cloud presence. EORC is advancing collaboration projects with organizations in Indonesia, Vietnam and other countries, and the Asian Development Bank. These are for various countries to be able to collect agricultural statistics data much effectively using this software and ALOS-2 data.

■ Development of the Agro-meteorological Information Service System (JASMIN) for assessing Crop Conditions

Spatial Distribution Map; Current Agro-meteorological Conditions (upper) and Difference from Average Year Conditions (lower)

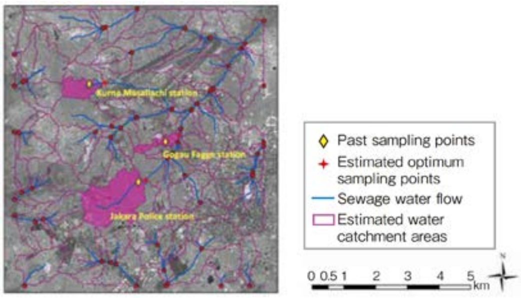
Time series –variation of each agro-meteorology

Crop growth is strongly related to agro-meteorological factors such as solar radiation, temperature and the water environment. Therefore, when a wide range and timely agro-meteorological data can be obtained, it is very useful to assess crop conditions on an entire country scale. The system "JASMIN (JAXA's Satellite based Monitoring Network system for FAO AMIS outlook) (http://suzaku.eorc.jaxa.jp/JASM/index.html) has been developed so the latest conditions of precipitation, soil moisture, solar radiation etc., can be accessed through the web site. For various agro-meteorological information data items, using this system, current conditions and the difference compared to average year conditions can be comprehensively assessed. Also, EORC works on research for estimating main crops short-term production using such information and crop models.

2.8. Public Health

It is concerning that environmental changes including temperature or precipitation changes accompanied by global warming can cause health hazards directly (heatstroke, circulatory disease or respiratory illness, etc.) or indirectly (Malaria, Cholera, polio or other infectious diseases). Such disease outbreaks cannot be predicted at an early stage and preventive measures cannot be taken, which is one reason why they can cause extensive damage. It has been pointed out that environmental changes associated with precipitation, temperature and topography are connected to the occurrence of health hazards. However, in developing countries, the surveillance system for such environmental information is inadequate. EORC makes a great effort to advance research and development for early warning systems for infectious diseases using satellites' earth observations. This is in cooperation with research institutes including universities and international organizations.

■ Effective Use of Digital Elevation Models to Monitor the Spread of Poliovirus



Water Catchment Area Estimation Results collected effectively using the ALOS Digital Elevation Model

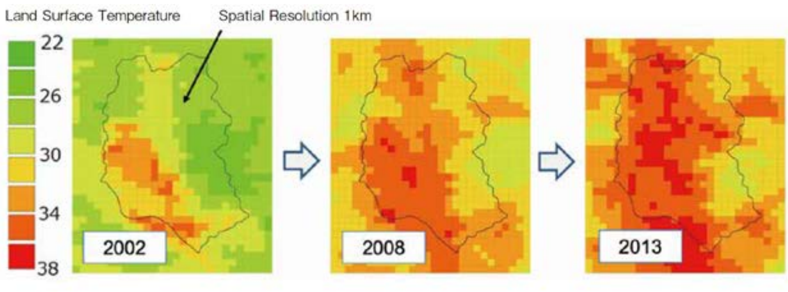
For WHO (World Health Organization), it is an urgent task to construct a viral infection situation data acquisition system, with periodical sampling of sewage water. For this purpose, it is important to identify efficient sampling points considering sewage water flow. In Nigeria, EORC has demonstrated that the water catchment areas can be identified (purple areas) and the selection of sewage water sampling points (red cross points) can be refined, by water analysis using the ALOS PRISM digital elevation model (AW3D), in cooperation with WHO.

■ Surveillance of Lake Victoria for Early Warning of Cholera


Lake Victoria's Surface Image from ALOS AVHIR-2

It has been pointed out that water hyacinth growing on Lake Victoria could possibility transmit cholera germs. Therefore, it is highly anticipated that the expansion of the water hyacinth growing area can be estimated based on the satellite data obtained by the AVNIR2 sensor etc., aboard the Advanced Land Observation Satellite "DAICHI" (ALOS). EORC performs the research jointly with the Research Institute of Tropical Medi- cine, Nagasaki University. Together they estimate the relation- ship between the water hyacinth growing area and epidemio- logical data such as the number of cholera patients based on satellite data.

■ Urban Heat Environment Surveillance for the Analysis of Diarrhea Cause Risk



Land Surface Temperature Change in Dhaka, Bangladesh

Urban heat island phenomena have developed due to drastic increases in urbanization. Heat conditions of urban cities have changed greatly. It has been pointed out that heat exposure estimates based on land surface temperature data from satellite observations would be an index for infections diseases including diarrhea, etc. EORC conducts research on the relationship between them, jointly with the Graduate School of Medicine, the University of Tokyo.