JAXA'S FUTURE EARTH OBSERVATION MISSIONS FOR METEOROLOGICAL AND CLIMATOLOGICAL APPLICATIONS

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Abstract

Japan Aerospace Exploration Agency (JAXA)'s space systems are regarded as components of an integrated observation system, such as an information gathering and warning system for disaster and crisis management or an integrated global environment monitoring and prediction system, which are dedicated to the corresponding to the Societal Benefit Areas of Global Earth Observation System of Systems (GEOSS). From 2011 to 2013, JAXA will launch several satellite missions, including international cooperated missions to monitor environmental changes, and contribute to meteorological and climatological researches. This paper will highlight JAXA’s current and future Earth observation satellites and missions.

INTRODUCTION

The Global Earth Observation System of Systems (GEOSS) was established through international cooperation in February 2005. The concept of GEOSS is to realize a future wherein decisions and actions for the benefit of humankind are formulated by coordinated, comprehensive, and sustained Earth observations through government-level commitments. GEOSS will provide comprehensive, coordinated, and sustained observations of the Earth system to improve the monitoring of the state of the Earth, increase our understanding of Earth’s processes, and enhance predictions of the behaviour of the Earth system. It will enhance the delivery of benefits to society in the nine Societal Benefit Areas, including Disaster Mitigation, Climate, Water, Weather, Ecosystems, and so on. JAXA currently operates and will launch several satellite missions dedicated to the corresponding to the Societal Benefit Areas of GEOSS. Figure 1 shows JAXA’s current and planned missions, including international cooperated missions.

![Figure 1: Current JAXA’s operating and planned missions as of September 2009. Joint missions with national and international organizations are also included in the figure. Mission name in yellow denotes operating mission (satellite name and/or instrument name), and that in light blue denotes planned mission. Satellites over inner purple and outer blue orbits are Earth observation satellites. Satellites over middle green orbit are communication technology satellites.](image-url)
TROPICAL RAINFALL MEASURING MISSION (TRMM):

The Tropical Rainfall Measuring Mission (TRMM) satellite was launched by H-II rocket No. 6 in November 1997, and continues its observation more than 11 years later. TRMM is joint mission between JAXA (former National Space Development Agency of Japan), Japanese National Institute of Information and Communications Technology (NICT) (former Communication Research Laboratory), and the U.S. National Aeronautics and Space Administration (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.

Recently, JAXA began to provide the Latent Heating research products via internet (http://www.eorc.jaxa.jp/TRMM/lh/index.html). The algorithm is based on the Spectral Latent Heating (SLH) algorithm (Shige et al., 2004, 2007, 2008), developed by joint study between the University of Tokyo, Osaka Prefecture University, and JAXA. The algorithm uses three-dimensional information of PR, such as convective/stratiform classification, precipitation top height, precipitation rates at the surface, and melting level, to retrieve heating profiles utilizing lookup tables. Figure 2 shows latent heat distribution by SLH algorithm during December, January, and February between 1998 and 2007. The data expected to be utilized for evaluation of global water and energy cycle and for improvement of climate models.

![Figure 2: Climatology of latent heating at altitude of 7.5km (upper) and of 2 km (lower) obtained by Spectral Latent Heating (SLH) algorithm.](image)

ADVANCED MICROWAVE SCANNING RADIOMETER FOR EOS (AMSR-E):

The Advanced Microwave Scanning Radiometer for EOS (AMSR-E) onboard NASA’s EOS Aqua satellite still continues its observation over 7-years after the launch on May 4, 2002. AMSR-E is multi-frequency microwave radiometer with dual polarization capability, developed by JAXA. It has C-band channels for estimating Sea Surface Temperature (SST) and soil moisture. AMSR-E has high-spatial resolution compared to existing instruments by large size antenna of 1.6 m.
C-band (6.9 GHz) of AMSR-E is indispensable frequency for retrieving Sea Surface Temperature (SST) as well as soil moisture. Since microwave measurement can estimate SST through clouds, it can provide cloud-through frequent SST mapping compared to SST estimated by Infrared (IR) instruments. AMSR-E can provide information regarding SST under typhoon (Figure 3). As typhoons go over the ocean, their footprints of colder SST are left. This is due to the stirring and upwelling effects caused by the strong winds of typhoon. Microwave technique is capable of observing this kind of phenomenon, which is usually difficult for IR observations due to the extensive coverage of clouds by typhoon.

**Figure 3:** Example of Sea Surface Temperature estimate by AMSR-E for 16 September 2006, onto which picture of JMA MTSAT-1 cloud image was superimposed. SST decrease (yellow) along with typhoon track in southwest of Japan is clearly seen. This decrease is due to the stirring and upwelling effects caused by strong winds of typhoon.

**GLOBAL CLIMATE CHANGE OBSERVATION MISSION (GCOM):**

Global Change Observation Mission (GCOM) is planned as the comprehensive observation system of the Earth System’s essential variables of atmosphere, ocean, land, cryosphere, and ecosystem. Most of these observations are expected to provide data commonly useful to the climate research and the meteorology. Additionally, the mission is designed to find out the traces of human-induced environmental changes, such as deforestations, forest fires, air and water quality changes to distinguish the human-induced changes and the natural cyclic changes. GCOM consists of two medium size of satellites; GCOM-W (water) will carry the Advanced Microwave Scanning Radiometer 2 (AMSR2), which is being developed based on the experience of the AMSR-E on EOS Aqua satellite; and GCOM-C (climate) will carry the Second Generation Global Imager (SGLI). As shown in Figure 4, three consecutive generations of GCOM satellites with one year overlap in orbit enables over 13 years observation in total. GCOM first generation satellites, GCOM-W1 and GCOM-C1, are planned to be launched in Japanese Fiscal Year (JFY) of 2011 and 2013, respectively.

**Figure 4:** GCOM mission concept. GCOM will consist of 2 satellite series (GCOM-W and C) spanning 3 generations in order to perform uniform and stable global observations for 13 years.
GCOM-W satellite:
Targets of the GCOM-W satellite are water-energy cycle, and will carry the AMSR2. AMSR2 will continue AMSR-E observations of water vapor, cloud liquid water, precipitation, SST, sea surface wind speed, sea ice concentration, snow depth, and soil moisture. Basic characteristics including center frequency, bandwidth, receiver noise, polarization, instantaneous Field of View (FOV), and sampling interval of the AMSR2 instrument are indicated in Table 1. Following improvements of AMSR2 instrument are planned based on experience in the AMSR-E mission; a) Deployable main reflector system with 2.0 m diameter; b) Frequency channel set is identical to that of AMSR-E except additional 7.3 GHz channel for radio frequency interference mitigation; and c) Two-point external calibration with the improved HTS. In addition, deep-space maneuver will be considered to check the consistency between main reflector and Cold Sky Mirror (CSM). JAXA is currently discussing with NASA that GCOM-W1 will join the A-train. Benefits of joining the A-train are precise inter-calibration between AMSR-E and AMSR2 and synergy with the other A-Train instruments for new Earth science research.

<table>
<thead>
<tr>
<th>Center Freq. [GHz]</th>
<th>Band Width [MHz]</th>
<th>NE Δ T[K]</th>
<th>Polarization</th>
<th>Beam Width [deg.] (Ground resolution [km])</th>
<th>Sampling interval [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.925 / 7.3</td>
<td>350</td>
<td>&lt; 0.34/0.43</td>
<td>V and H</td>
<td>1.8 (35 x 62)</td>
<td>10</td>
</tr>
<tr>
<td>10.65</td>
<td>100</td>
<td>&lt; 0.70</td>
<td></td>
<td>1.2 (24 x 42)</td>
<td></td>
</tr>
<tr>
<td>18.7</td>
<td>200</td>
<td>&lt; 0.70</td>
<td></td>
<td>0.65 (14 x 22)</td>
<td></td>
</tr>
<tr>
<td>23.8</td>
<td>400</td>
<td>&lt; 0.60</td>
<td></td>
<td>0.75 (15 x 26)</td>
<td></td>
</tr>
<tr>
<td>36.5</td>
<td>1000</td>
<td>&lt; 0.70</td>
<td></td>
<td>0.35 (7 x 12)</td>
<td></td>
</tr>
<tr>
<td>89.0 A/B</td>
<td>3000</td>
<td>&lt; 1.20/1.40</td>
<td></td>
<td>0.15 (3 x 5)</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Frequency channels and resolutions of AMSR2 instrument

GCOM-C1 satellite:
Targets of GCOM-C are carbon cycle and radiation budget relating to the global environmental change, and will carry SGLI, which is a radiometer of 380-12000 nm (Table 2) as a follow-on mission of ADEOS-II/GLI. SGLI will observe aerosols, cloud, vegetation, ocean colour, sea and land surface temperature, snow and ice, etc.. SGLI system consists of two components; SGLI-VNR (Visible & Near infrared push-broom Radiometer); and SGLI-IRS (shortwave & thermal InfraRed Scanner) to optimize optics for each wavelength range. SGLI-VNR consists of 11-channel non-polarimetric telescope and 2-channel along-track slant polarimetric telescope systems. SGLI-IRS consists of 4-channel shortwave infrared and 2-channel thermal infrared systems. The SGLI features are finer spatial resolution (250 m (VNI) and 500 m (T)) and polarization/along-track slant view channels (P), which will improve land, coastal, and aerosol observations. SGLI-VNR 250 m resolution data will enable to detect more fine structure in the coastal area such as river outflows, regional blooms, and small currents.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Weavelength</th>
<th>Bandwidth</th>
<th>Lmax</th>
<th>IFOV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VN, P, SW: nm</td>
<td>T: μm</td>
<td>μm</td>
<td></td>
</tr>
<tr>
<td>VN1</td>
<td>380</td>
<td>10</td>
<td>210</td>
<td>250</td>
</tr>
<tr>
<td>VN2</td>
<td>412</td>
<td>10</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>VN3</td>
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<tr>
<td>VN4</td>
<td>490</td>
<td>10</td>
<td>120</td>
<td>250</td>
</tr>
<tr>
<td>VN5</td>
<td>530</td>
<td>20</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>VN6</td>
<td>565</td>
<td>20</td>
<td>90</td>
<td>250</td>
</tr>
<tr>
<td>VN7</td>
<td>673.5</td>
<td>20</td>
<td>62</td>
<td>250</td>
</tr>
<tr>
<td>VN8</td>
<td>673.5</td>
<td>20</td>
<td>210</td>
<td>250</td>
</tr>
<tr>
<td>VN9</td>
<td>763</td>
<td>12</td>
<td>350</td>
<td>1000</td>
</tr>
<tr>
<td>VN10</td>
<td>868.5</td>
<td>20</td>
<td>30</td>
<td>250</td>
</tr>
<tr>
<td>VN11</td>
<td>868.5</td>
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<td>250</td>
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<tr>
<td>P1</td>
<td>673.5</td>
<td>20</td>
<td>250</td>
<td>1000</td>
</tr>
<tr>
<td>P2</td>
<td>868.5</td>
<td>20</td>
<td>300</td>
<td>1000</td>
</tr>
<tr>
<td>NW1</td>
<td>1050</td>
<td>20</td>
<td>248</td>
<td>1000</td>
</tr>
<tr>
<td>SW2</td>
<td>1380</td>
<td>20</td>
<td>103</td>
<td>1000</td>
</tr>
<tr>
<td>SW3</td>
<td>1630</td>
<td>200</td>
<td>50</td>
<td>250</td>
</tr>
<tr>
<td>SW4</td>
<td>2210</td>
<td>50</td>
<td>20</td>
<td>1000</td>
</tr>
<tr>
<td>T1</td>
<td>10.8</td>
<td>0.74</td>
<td>340</td>
<td>500 (250)</td>
</tr>
<tr>
<td>T2</td>
<td>12.0</td>
<td>0.74</td>
<td>340</td>
<td>500 (250)</td>
</tr>
</tbody>
</table>

Table 1: Channels and resolutions of SGLI instrument. “P.” denotes “Polarization.”
Second generation of GCOM-W satellite:
Currently, discussion regarding the second generation of GCOM-W satellite (GCOM-W2) is underway. GCOM-W2 is to be launched 4-year after the launch of GCOM-W1 satellite, to achieve 1-year overlap to GCOM-W1/AMSR2 for calibration. AMSR2 improvement study for GCOM-W2 satellite recently has started. Discussion and study includes addition of high-frequency channels to AMSR2. JAXA is also discussing with the U.S. National Oceanic and Atmospheric Administration (NOAA) and NASA Jet Propulsion Laboratory (JPL) that U.S. provided scatterometer, a follow-on instrument to SeaWinds, will be installed on GCOM-W2. Sensor-level synergy for scatterometer is rain flag and correction in algorithm using microwave radiometer data. That for microwave radiometer is improvement of brightness temperature model as a function of wind vector. Other advantages in cross validation, and active and passive microwave synergy are highly expected. For example, combination of SST obtained by microwave radiometer with microwave scatterometer can provide quantitative view of convergence/divergence by wind vector observations.

GLOBAL PRECIPITATION MEASUREMENT (GPM):
Global Precipitation Measurement (GPM) started as an international mission and follow-on and expand mission of the TRMM satellite 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. As shown in Figure 5, an important goal for the GPM mission is the frequent measurement of global precipitation using a GPM core satellite, which is jointly developed by U.S. and Japan, and a constellation of multiple satellites, which are developed by each international partner that will carry passive microwave radiometers and/or microwave sounders. The accurate measurement of precipitation will be achieved by two sensors onboard the GPM Core satellite which will be launched in JFY 2013; the Dual-frequency Precipitation Radar (DPR) developed by JAXA and NICT, and the GPM Microwave Imager (GMI) developed by NASA. The roles of the GPM core 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.

**Core Satellite**
- Understand the horizontal and vertical structure of rainfall and its microphysical element.
- Provide training for constellation radiometers
  - Dual-frequency Precipitation Radar (DPR: 13.6GHz, 35.5GHz)
    - Horizontal resolution: ~5 km
    - Vertical resolution: 250/500 m
    - Swath: ~245 km
  - GPM Microwave Imager (GMI)
  - July 2013, H2-A launch
  - Non-sun-synchronous orbit
    - Inclination angle: ~65°
    - Altitude: ~407 km

**Constellation Satellites**
- Provide enough sampling to reduce uncertainty in short-term rainfall accumulations.
- Extend scientific and societal applications
  - Small satellites with microwave radiometer/sounder
  - Covering 80% of globe in 3-hrs
  - Sun-synchronous polar orbit or Non-sun-synchronous orbit
  - International partners: NOAA, NASA, JAXA, CHEST/ISRO, etc.

**Figure 5: Overview of the GPM Mission.**

Generation and dissemination of Global Rainfall Map with high frequency and accuracy will contribute to various applications such as weather, flood forecast, agriculture, and more. JAXA has developed and operates prototype of the Global Precipitation Map algorithm in near-real-time (Figure 6) since October 2008 (Ushio and Kachi, 2009), and hourly and 0.1-degree resolution binary data and images available at [http://sharaku.eorc.jaxa.jp/GSMaP/](http://sharaku.eorc.jaxa.jp/GSMaP/). The algorithms are based on outcomes from the Global Satellite Mapping for Precipitation (GSMaP) project, which was sponsored by the Japan Science and Technology Agency (JST) under the Core Research for Evolutional Science and
Technology (CREST) framework between 2002 and 2007 (Okamoto et al., 2005; Aonashi et al., 2009; Ushio et al., 2009). Near-real-time data is distributed via internet and utilized in various areas, such as science researches (model validation, data assimilation, typhoon study, etc.), weather forecast/service, flood warming and rain analysis over river basin, oceanographic condition forecast, agriculture, and teaching.

![Image](image1.png)

Figure 6: Hourly rainfall image of GSMaP near-real-time product, onto which cloud images of Geostationary satellites were superimposed. Typhoon "MORACOT," which caused serious damages in Taiwan, was observed.

**CLOUD PROFILING RADAR (CPR) FOR EARTHCARE MISSION**

Earth Clouds, Aerosols and Radiation Explorer (EarthCARE) is a joint mission between European Space Agency (ESA) and Japan, planned for launch in JFY 2013 (Figure 7). JAXA and NICT will provide the Cloud Profiling Radar (CPR), which is able to measure vertical Doppler speeds. The objective of EarthCARE mission is to retrieve vertical profiles of cloud with its Doppler velocities and aerosol, and characteristics of the radiative and micro-physical properties so as to determine flux gradients within the atmosphere and fluxes at the Earth’s surface, as well as to measure directly the fluxes at the top of the atmosphere and also to clarify the processes involved in aerosol-cloud and cloud-precipitation-convection interactions. Other three instruments, Atmospheric Lidar (ATLID), Multi-Spectral Imager (MSI) and Broadband Radiometer (BBR), will be developed by ESA.

Synchronized observation with four instruments provides measurements of cloud, aerosol vertical distribution, micro-physics properties, and the vertical velocity of convective motion. Expected outcomes of EarthCARE mission is contribution to the elucidation of process of Earth radiation budge and the improvement of climate change model prediction accuracy.

![Image](image2.png)

Figure 7: Observation concept of EarthCARE mission.
TOWARD INTEGRATED UTILIZATION OF MULTI-SATELLITE DATA:

This paper illustrates JAXA’s current and future satellites and missions contributing to environmental monitoring and meteorology, climatology and hydrological cycle researches. Forthcoming satellite missions dedicated and/or contribute to monitor global environment and hydrological cycles are ahead.

Considering the increase of missions in the near future, JAXA recently started cross-cutting research initiatives in the thematic fields consists with “water cycle”, “ecosystems” and “disaster prevention”, in addition to current mission-oriented research approaches (Figure 8). Those research activities are expected to demonstrate that satellite data can contribute to the societal systems in the future in fields connected directly with global warming, water and energy cycle, ecosystems, etc., where results cannot be obtained easily by a single satellite project.

Cooperation with various research communities outside JAXA has been also stated regarding data utilization in the fields of flood forecasting, numerical models, and ecosystems. Those collaborative activities will accelerate utilization of transdisciplinary observation of JAXA’s satellite missions in broader fields.

Figure 8: Concept of cross-cutting/interdisciplinary science at JAXA.

REFERENCES


