JAXA Earth Observation Missions

Keiji Imaoka + many contributors

Earth Observation Research Center (EORC)
Japan Aerospace Exploration Agency (JAXA)

Mini-Workshop on A-Train Science
Tokyo, Japan
March 8, 2013
Current and Near-Term Future Missions
Demonstrate long-term global observation of various geophysical parameters for understanding climate variability and water cycle.

Two medium-sized satellites with three generations to ensure 10-15 years stable data records.
Overview of GCOM Products

Atmosphere
- cloud properties
- aerosol properties
- cloud liquid water
- cloud depth
- precipitation
- sea ice concentration
- sea surface temp.
- land cover
- land surface temperature
- water vapor
- soil moisture
- sea surface wind speed
- PAR
- above-ground biomass
- ocean color
- sea surface temp.
- snow surface properties
- snow surface temp.
- snow surface properties
- snow depth
- snow ice distribution
- aerosol properties

Land
- primary production
- PAR
- ocean color
- sea surface temp.
- land cover
- land surface temperature
- water vapor
- soil moisture
- sea surface wind speed
- precipitation
- sea ice concentration
- snow surface properties
- snow surface temp.
- snow depth
- snow ice distribution
- aerosol properties

Carbon Cycle
- PAR
- ocean color
- sea surface temp.
- land cover
- land surface temperature
- water vapor
- soil moisture
- sea surface wind speed
- precipitation
- sea ice concentration
- snow surface properties
- snow surface temp.
- snow depth
- snow ice distribution
- aerosol properties

Cryosphere
- snow surface properties
- snow surface temp.
- snow depth
- snow ice distribution
- aerosol properties

Radiation Budget
- PAR
- ocean color
- sea surface temp.
- land cover
- land surface temperature
- water vapor
- soil moisture
- sea surface wind speed
- precipitation
- sea ice concentration
- snow surface properties
- snow surface temp.
- snow depth
- snow ice distribution
- aerosol properties

Ocean
- PAR
- ocean color
- sea surface temp.
- land cover
- land surface temperature
- water vapor
- soil moisture
- sea surface wind speed
- precipitation
- sea ice concentration
- snow surface properties
- snow surface temp.
- snow depth
- snow ice distribution
- aerosol properties
GCOM 1\textsuperscript{st} Generation Satellites

- 2 types of medium-sized satellites and 3 generations: 10-15 years observation

“SHIZUKU”

<table>
<thead>
<tr>
<th>GCOM-W1 (Water)</th>
<th>GCOM-C1 (Climate)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Instrument</strong></td>
<td><strong>Second-generation Global Imager</strong></td>
</tr>
<tr>
<td>Advanced Microwave Scanning Radiometer-2</td>
<td>Sun Synchronous orbit</td>
</tr>
<tr>
<td>Orbit</td>
<td>Altitude: 798km (on Equator)</td>
</tr>
<tr>
<td>Altitude: 699.6km (on Equator)</td>
<td>Inclination: 98.6 deg.</td>
</tr>
<tr>
<td>Inclination: 98.2 degrees</td>
<td>Local sun time: 10:30+/− 15min</td>
</tr>
<tr>
<td>Local sun time: 13:30+/− 15min</td>
<td>Size</td>
</tr>
<tr>
<td>Size</td>
<td>4.6m (X) * 16.3m (Y) * 2.8m (Z) (on orbit)</td>
</tr>
<tr>
<td>5.1m (X) * 17.5m (Y) * 3.4m (Z) (on orbit)</td>
<td>Mass</td>
</tr>
<tr>
<td>1991kg</td>
<td>2093kg</td>
</tr>
<tr>
<td>Power gen.</td>
<td>Power gen.</td>
</tr>
<tr>
<td>More than 3880W (EOL)</td>
<td>More than 4000W (EOL)</td>
</tr>
<tr>
<td>Launch</td>
<td>Launch</td>
</tr>
<tr>
<td>May 18, 2012</td>
<td>JFY 2015 (TBD)</td>
</tr>
<tr>
<td>Design Life</td>
<td>Design Life</td>
</tr>
<tr>
<td>5-years</td>
<td>5-years</td>
</tr>
</tbody>
</table>
SGLI Instrument

- Improvement of land, coastal, and aerosol observations.
  - fine (250m) spatial resolution
  - polarization/along-track slant view

### GCOM-C SGLI characteristics (Current baseline)

<table>
<thead>
<tr>
<th>Orbit</th>
<th>Sun-synchronous (descending local time: 10:30) Altitude: 798km, Inclination: 98.6deg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch Date</td>
<td>Jan. 2014 (HII-A)</td>
</tr>
<tr>
<td>Mission Life</td>
<td>5 years (3 satellites; total 13 years)</td>
</tr>
<tr>
<td>Scan</td>
<td>Push-broom electric scan (VNR: VN &amp; P) Wisk-broom mechanical scan (IRS: SW &amp; T)</td>
</tr>
<tr>
<td>Scan width</td>
<td>1150km cross track (VNR: VN &amp; P) 1400km cross track (IRS: SW &amp; T)</td>
</tr>
<tr>
<td>Digitalization</td>
<td>12bit</td>
</tr>
<tr>
<td>Polarization</td>
<td>3 polarization angles for P</td>
</tr>
<tr>
<td>Along track</td>
<td>Nadir for VN, SW and T, +45 deg and -45 deg for P</td>
</tr>
<tr>
<td>On-board calibration</td>
<td>VN: Solar diffuser, Internal lamp (LED, halogen), Lunar by pitch maneuvers (~once/month), and dark current by masked pixels and nighttime obs. SW: Solar diffuser, Internal lamp, Lunar, and dark current by deep space window T: Black body and dark current by deep space window All: Electric calibration</td>
</tr>
</tbody>
</table>

### SGLI channels

<table>
<thead>
<tr>
<th>CH</th>
<th>VN, P, SW: nm</th>
<th>T: µm</th>
<th>L&lt;sub&gt;std&lt;/sub&gt;</th>
<th>L&lt;sub&gt;max&lt;/sub&gt;</th>
<th>SNR at L&lt;sub&gt;std&lt;/sub&gt;</th>
<th>FOV m</th>
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<tbody>
<tr>
<td>VN1</td>
<td>380</td>
<td>10</td>
<td>60</td>
<td>210</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>VN2</td>
<td>412</td>
<td>10</td>
<td>75</td>
<td>250</td>
<td>400</td>
<td>250</td>
</tr>
<tr>
<td>VN3</td>
<td>443</td>
<td>10</td>
<td>64</td>
<td>400</td>
<td>300</td>
<td>250</td>
</tr>
<tr>
<td>VN4</td>
<td>490</td>
<td>10</td>
<td>53</td>
<td>120</td>
<td>400</td>
<td>250</td>
</tr>
<tr>
<td>VN5</td>
<td>530</td>
<td>20</td>
<td>41</td>
<td>350</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>VN6</td>
<td>565</td>
<td>20</td>
<td>33</td>
<td>90</td>
<td>400</td>
<td>250</td>
</tr>
<tr>
<td>VN7</td>
<td>673.5</td>
<td>20</td>
<td>23</td>
<td>62</td>
<td>400</td>
<td>250</td>
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<tr>
<td>VN8</td>
<td>673.5</td>
<td>20</td>
<td>25</td>
<td>210</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>VN9</td>
<td>763</td>
<td>12</td>
<td>40</td>
<td>350</td>
<td>1200(@1km)</td>
<td>250</td>
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<tr>
<td>VN10</td>
<td>868.5</td>
<td>20</td>
<td>8</td>
<td>30</td>
<td>400</td>
<td>250</td>
</tr>
<tr>
<td>VN11</td>
<td>868.5</td>
<td>20</td>
<td>30</td>
<td>300</td>
<td>200</td>
<td>250</td>
</tr>
<tr>
<td>P1</td>
<td>673.5</td>
<td>20</td>
<td>25</td>
<td>250</td>
<td>250</td>
<td>1000</td>
</tr>
<tr>
<td>P2</td>
<td>868.5</td>
<td>20</td>
<td>30</td>
<td>300</td>
<td>250</td>
<td>1000</td>
</tr>
<tr>
<td>SW1</td>
<td>1050</td>
<td>20</td>
<td>57</td>
<td>248</td>
<td>500</td>
<td>1000</td>
</tr>
<tr>
<td>SW2</td>
<td>1380</td>
<td>20</td>
<td>8</td>
<td>103</td>
<td>150</td>
<td>1000</td>
</tr>
<tr>
<td>SW3</td>
<td>1630</td>
<td>200</td>
<td>3</td>
<td>50</td>
<td>57</td>
<td>250</td>
</tr>
<tr>
<td>SW4</td>
<td>2210</td>
<td>50</td>
<td>1.9</td>
<td>20</td>
<td>211</td>
<td>1000</td>
</tr>
<tr>
<td>T1</td>
<td>10.8</td>
<td>0.7</td>
<td>300</td>
<td>340</td>
<td>0.2</td>
<td>500/250</td>
</tr>
<tr>
<td>T2</td>
<td>12.0</td>
<td>0.7</td>
<td>300</td>
<td>340</td>
<td>0.2</td>
<td>500/250</td>
</tr>
</tbody>
</table>

- 250m over land or coastal area, and 1km over offshore
- Multi-angle obs. for 674nm and 869nm
- 250m-mode possibility
Spaceborne Cloud & Precipitation Radar Development


TRMM/PR (by JAXA/NICT)
Ku-band (13.8GHz)

GPM/DPR (by JAXA/NICT)
Ku-band (13.6GHz)
Ka-band (35.5GHz)

EarthCARE/CPR (by JAXA/NICT)
W-band (94.05GHz) (Doppler radar)

CloudSat/CPR (by NASA)
W-band (94GHz)

1997 ~ Today

2006 ~ Today

2014 ~

2015 ~

long term global precipitation record
full spectrum of cloud and precipitation (cloud - weak rain - heavy rain)
Focused on rainfall observation. First instantaneous rainfall observation by three different sensors (PR, TMI, VIRS). PR, active sensor, can observe 3D structure of rainfall.

Targeting tropical and subtropical region, and chose non-sun-synchronous orbit (inc. angle 35 degree) to observe diurnal variation.

**Launch**
- 28 Nov. 1997 (JST)

**Altitude**
- About 350km (since 2001, boosted to 402km to extend mission operation)

**Inc. angle**
- About 35 degree, non-sun-synchronous orbit

**Design life**
- 3-year and 2month (still operating)

**Instruments**
- Precipitation Radar (PR)
- TRMM Microwave Imager (TMI)
- Visible Infrared Scanner (VIRS)
- Lightning Imaging Sensor (LIS)
- CERES (not in operation)
Typhoon MORAKOT (09W): Aug. 5 – 10, 2009 (Big impact in Chinese Taipei)

- Rapidly changing precipitation phenomena need frequent observations.
- Global rainfall map merging TRMM, polar orbiting microwave radiometer/sounders, and geostationary infrared radiometers.

http://sharaku.eorc.jaxa.jp/GSMaP/
GPM: An international satellite mission to be launched by JAXA and NASA in 2014 for precipitation measurements worldwide

Core Satellite (JAXA, NASA)
- Dual-frequency precipitation radar (DPR)
- GPM Microwave Imager (GMI)
  - Precipitation with high precision
  - Discrimination between rain and snow
  - Adjustment of data from constellation satellites (The core satellite will fly in non-sun-synchronous orbit.)

Constellation Satellites (International Partners)
- Microwave radiometers
- Microwave sounders
  - Global precipitation every 3 hours

Improve the accuracy of both long-term and short-term weather forecasts
Improve water resource management in river control and irrigation systems for agriculture
Dual-frequency precipitation radar (DPR) consists of
- Ku-band (13.6GHz) radar: KuPR (similar to TRMM/PR)
  and
- Ka-band (35.5GHz) radar: KaPR

The DPR was developed by JAXA and NICT.

Range resolution = 250m and 500m

KuPR (13.6GHz)
Swath width = 245km

KaPR (35.5GHz)
Swath width = 120km

Microwave radiometer
Swath width = 800 km

Flight direction
407 km altitude,
65 deg inclination

GMI: GPM Microwave Imager

GMI

DPR

5km
Preparation in Progress

KuPR PFM

KaPR PFM under integration

Satellite Photo Credit: NASA
To reduce the uncertainties in global warming prediction by measuring the three dimensional structure of clouds and aerosols, which are most uncertain parameter in the numerical climate models.

- Joint Mission by Europe and Japan
- 3 years lifetime
- 400 km altitude
- Sun-synchronous orbit (Local time: 14:00)
EarthCARE Instruments

Four instruments
- Cloud Profiling RADAR (JAXA/NICT)
- Atmospheric LIDAR (ESA)
- Multi-Spectral Imager (ESA)
- Broad Band Radiometer (ESA)

CPR Engineering Model
Overview of CPR

• EarthCARE CPR is the first millimeter-wave Doppler radar in space for Earth observation developed by JAXA and NICT.
• 94GHz of W-band is selected for center frequency to penetrate deep into the clouds from the orbit and retrieve the cloud vertical profiles and motions.
• The antenna employs offset Cassegrain type, and has a deployable main reflector with the largest aperture for W-band Earth observation satellite.
• CPR observes clouds along the sub-satellite track.
Monitoring global distribution of Greenhouse Gases from space.

Observe Carbon dioxide and Methane at 100-1000km spatial scale with relative accuracy of 1% (4ppm) for CO2 and 2% (34ppb) for CH4.

Joint project by JAXA, NIES (National Institute for Environmental Studies), and MOE (Ministry of the Environment). 

Launch: 23 January 2009 by H2A launch vehicle 

Mission lifetime: 5 years to 2014
TANSO = Thermal And Near infrared Sensor for carbon Observation

TANSO-FTS (Fourier Transform Spectrometer)

TANSO-CAI (Cloud and Aerosol Imager)
TANSO-FTS Spectral Coverage
**Advanced Land Observing Satellite - ALOS “DAICHI” -**

- **Operation:**
  - 24 Jan. 2006 by H-2A Rocket #8
  - 12 May 2011 Mission ended
  - ~22 Apr. 2011: Low Load Mode (LLM)
  - > 1,934 days = 5.3 years

- **Objectives:**
  - Cartography (1/25,000 scale)
  - Regional environmental monitoring
  - Disaster monitoring, etc.

**PRISM**
Panchromatic Remote sensing Instrument for Stereo Mapping

PRISM can acquire triplet stereo imageries by nadir-, forward-, and backward-radiometers with 2.5m spatial resolution in 35km swath.

**AVNIR-2**
Advanced Visible and Near-Infrared Radiometer type 2

AVNIR-2 can observe with 10m resolution in 70km swath, and it can be changed the observation area by pointing capability within +/-44 deg. in across track.

**PALSAR**
Phased Array type L-band Synthetic Aperture Radar

PALSAR can acquire the data in not only daytime but also nighttime as well as cloudy and rainy whether conditions.
Global and high resolution observation by radar and optical sensors

- **ALOS-2 (Radar)**
- **ALOS-3 (Optical)**

- High resolution (1-3 m) and wide observation area (50-350 km swath)
- Fine and clear images under the heavy rain or night condition

Launch: JFY2013
Launch: JFY2016 (Target)
Research Activities for Future Missions
Earth Observation utilizing ISS

- SMILES: Detection of atmospheric limb emission in the submillimeter wave range (624-650GHz) with high sensitivity. NICT and JAXA cooperation.
- JAXA is promoting EO missions such as:
  - Live broadcasting of global phenomena by astronauts
  - Kibo Exposed Facility payloads
    - Compact InfraRed Camera (CIRC)
    - CO2 Lidar, Doppler lidar, etc.
Candidates onboard Kibo-Exposed Facility on ISS

iLOVE
iss-jem Lidar Observation of Vegetation Environment

Tree canopy height, Biomass

APOLLO
Air Pollution Observing mission

Kibo-EF on ISS
UV-VIS/TIR/MW

• High-spatial resolution observation from low orbit (APOLLO: 1–2km, Other: 7–25km)
• Diurnal variation observation from low inclination orbit
Observation of canopy height by LiDAR (laser radar) with high accuracy to improve biomass estimations.

- Experimental proof for future carbon-balance monitoring system of forestry ecosystem.
- The vegetation lidar observes 3D-structure of vegetation including canopy-height, which will enable us to estimate the forestry biomass on the ground.
- To verify potential of biomass estimation with collaborative observation between the vegetation lidar and a L-band SAR system (such as ALOS-2).

Schematic diagram of the vegetation lidar mission.

Potential observational partner: ALOS-2/L-band SAR

Improve biomass estimations
Heritage of SAR (ALOS-2 L-band SAR)

**COMPIRA**

Coastal and Ocean measurement Mission with Precise and Innovative Radar Altimeter

**Wide-swath altimetry with interferometric SAR**

**X-band SAR antennas**

- COMPIRA measures sea surface height using two SAR antennas.
- Swath width: 160 km (80 km swath each in left and right side)

**Requirements for Wide-swath measurement of sea surface height**

Sea surface height / ocean currents

T/P, Jason-1, ERS-2, Envisatと漂流ブイデータから計算した平均流速場

**X-band SAR Cross-track Interferometry**
Measurement of absolute sea surface height with wide-swath and high precision will be realized by combining SHIOSAI (Interferometric SAR sensor; to obtain relative height) and nadir pointing radar altimeter (to obtain absolute height).
Observation of atmospheric pollution in Asia and trans-boundary pollution

Frequent sounding of temperature, water vapor and wind profiles.

Specifications

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>MWIR, LWIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSD</td>
<td>4km X 4km</td>
</tr>
<tr>
<td>Area</td>
<td>Sphere</td>
</tr>
<tr>
<td>Time res.</td>
<td>1 hour</td>
</tr>
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</table>
Expanding the GOSAT FTS technology

FTS → Imaging FTS using 2D array detector

GOSAT observation

Imaging FTS observation
Large-Aperture MWR

- Experiences and existing technologies in microwave radiometer (MWR) and large deployable reflector (LDR).

- High-res requirements for lower frequency channels (C and L) to retrieve soil moisture, SST, and SSS.

- Applications in agriculture, food security, and ocean safety.

Large-aperture low-freq MWR

Target:
5km @ C-band
20km @ L-band
Submillimeter wave radiometer (190GHz – 1THz) can capture two dimensional columnar ice amount for both thick convective clouds and anvil clouds.
Concept of Super Low Altitude Satellite
✓ Much lower than LEO altitude: about 200km altitude
✓ Cancel the air drag effect by ion engine thrust in order to maintain the altitude
✓ Enable high performance earth observation by small resource sensor
  ➢ High spatial resolution in optical Earth observation
  ➢ Active sensing such as SAR and LIDAR with low electric power

“SLATS” is engineering test satellite before operational Super Low Altitude Satellites
✓ Verification of super low altitude satellite system, measurement of atmospheric density in super low altitude, and monitoring on-orbit data about atomic oxygen.

<table>
<thead>
<tr>
<th>Orbit</th>
<th>Mission: 250-180km Circular</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size (on-orbit)</td>
<td>2.5m(X) × 5.2m(Y) × 0.9m(Z)</td>
</tr>
<tr>
<td>Mass</td>
<td>about 400kg</td>
</tr>
<tr>
<td>Mission life</td>
<td>more than 1.5 year (dependent on injection orbit)</td>
</tr>
</tbody>
</table>

Mission sensor
1. AO Monitoring System (AMO)
   a) QCM Sensor and Controller (AOFS)
   b) Material Degradation Monitor (Optical Camera)(MDM)
2. Small Optical Sensor for imaging the earth (OPS)

Overview of Super Low Altitude Test Satellite (SLATS)
**Current and Near-Future JAXA EO Missions**

1. **GCOM-C**: Long-term observation of the horizontal distribution of aerosol, cloud, and ecosystem CO₂ absorption and discharge
2. **GCOM-W**: Long-term observation of water-cycle such as the snow/ice coverage, water vapor, and SST
3. **GOSAT**: Observation of distribution and flux of the atmospheric greenhouse gases, CO₂ and CH₄
4. **EarthCARE/CPR**: Observation of vertical structure of clouds and aerosols
5. **GPM/DPR**: Accurate and frequent observation of precipitation with active and passive sensors
6. **ALOS-2,3**: Fine resolution mapping by optical and SAR instruments
7. **ISS/JEM**: Demonstration of new missions (e.g., SMILES, GLISM, etc.)
Thank you for your attention.