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 its orbit is at noon in order to complement other SAR satellites which are in dawn-dusk orbits.

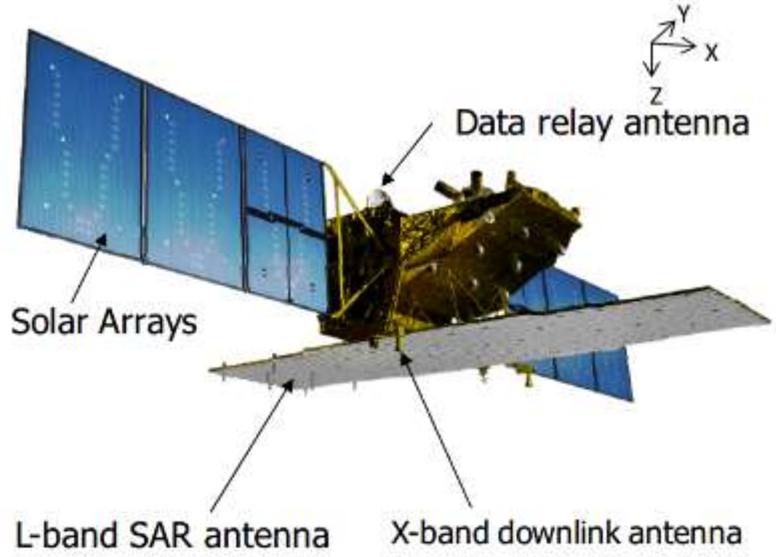


Fig. 1 ALOS-2 in-orbit configuration.

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
Design lifetime	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.

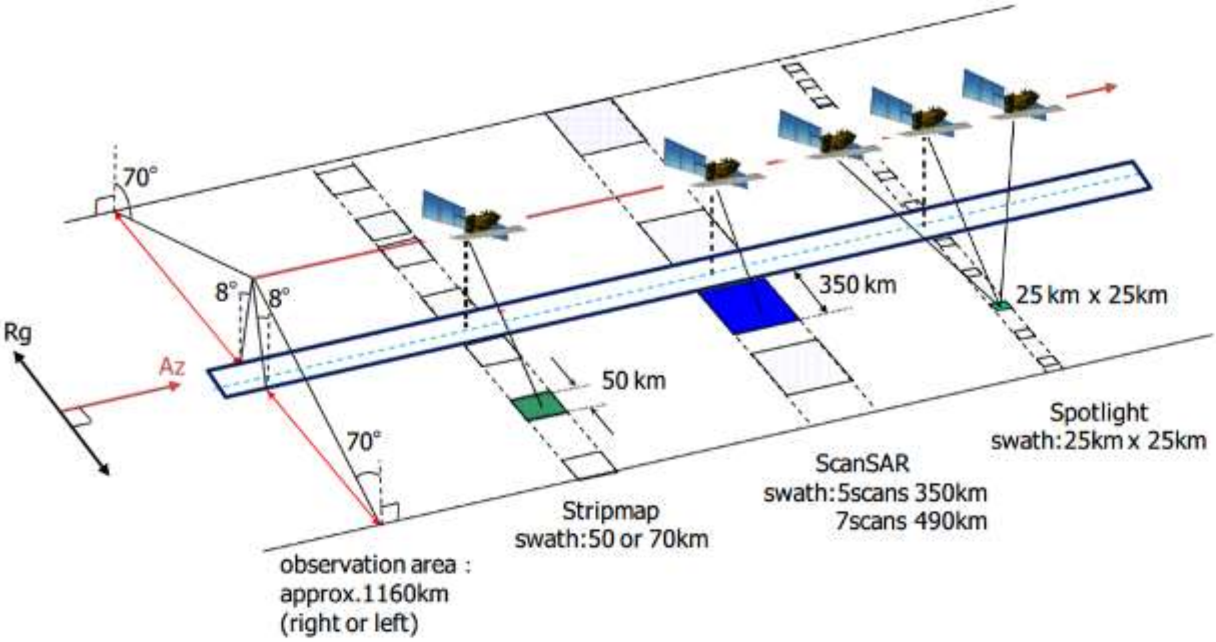


Fig. 2 PALSAR-2 observation modes.

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.

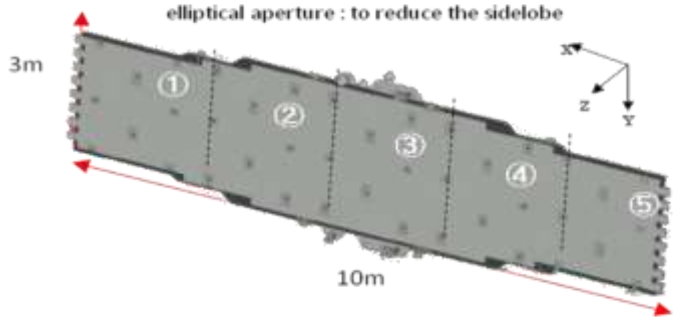


Fig. 3 PALSAR-2 antenna configuration.

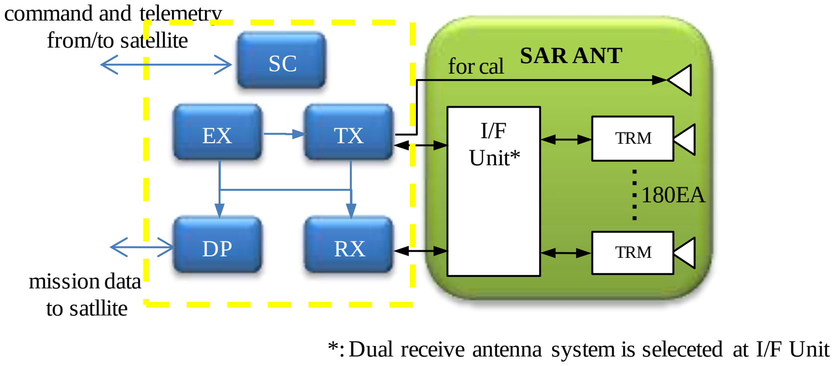


Fig. 4 PALSAR-2 system diagram.

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-3 (BOS-3) that is optimized as the background mission while the emergency observation is the highly prioterized operation for the disaster mitigations. The BOS-3 is open to the public through ALOS-2 i.e. https://www.eorc.jaxa.jp/ALOS-2/en/obs/pal2_obs_guide.htm

The BOS-3 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

OVERVIEW OF
THE ADVANCED LAND OBSERVING SATELLITE-3
(ALOS-3) MISSION

1. Introduction

The Advanced Land Observing Satellite-3 (ALOS-3) is the next high-resolution optical mission as a successor of the Advanced Land Observing Satellite (ALOS, "Daichi") in Japan Aerospace Exploration Agency (JAXA). ALOS-3 will be launched in JFY 2021 as current plan. The major mission objectives of ALOS-3 are

(1) to contribute safe and secure social including provisions for natural disasters, and

(2) to create and update geo-spatial information.

The wide-swath and high-resolution optical imager (WISH, as a tentative name) is designed to be achieved the mission objectives and consists of the panchromatic band and multispectral bands by six channels.

2. Specifications of ALOS-3 and Instrument (WISH)

Figure 1 shows in-orbit artificial image of ALOS-3, and Table 1 summarizes the specifications of the satellite. The satellite's orbit is kept as the sun-synchronous and sub-recurrent with 10:30 am of local sun time, but the repeat cycle is 35 days from 46 days of ALOS's one. This is enhanced observable frequency at middle and high latitude areas, however small pointing angle observations are necessary to cover the entire area in low latitudes.

Table 2 summarizes the current specifications of the WISH, which is considered to improve and enhance a fine resolution and global observation capabilities achieved by the Panchromatic Remote Sensing for Stereo Mapping (PRISM) and the Advanced Visible and Near Infrared Radiometer type-2 (AVNIR-2) onboard ALOS. For example, the ground sampling distance (GSD) is 0.8 m of WISH's panchromatic band compared with 2.5 m of PRISM, and 3.2 m for multi-spectral bands with 10 m of AVNIR-2, even the observation swath widths are same as 70 km at nadir, respectively.

For multi-spectral observation, two channels are added from AVNIR-2 i.e. Coastal and Red Edge that will contribute to bathymetry and environmental monitoring in coast regions, and to activation level monitoring in forests, vegetation and agricultural areas. The data quantization is also improved to 11 bits/pixel from 8 bits/pixel of PRISM and AVNIR-2. This improvement will contribute to obtain better image quality. On the other hand, this accrues a huge amount of mission data, therefore the Optical Data Relay Satellite (JDRS) that is also under developed, will be used to downlink them from space to ground.

Unfortunately, along-track stereo observation by multi-sensors like PRISM had not been selected, however the satellite has the body pointing capability within 60 deg. in cone-shape from nadir that will contribute in an emergency observation if a natural disaster happens for example. More detail about observation modes is introduced in Section 3.

Fig. 1 ALOS-3 in-orbit image.

Table 1 ALOS-3 specifications.

Items		Specifications
Orbit	Type	Sun-synchronous sub-recurrent
	Altitude	669 km at the equator
	Local Sun Time	10:30 am +/- 15 minutes at the descending node
	Revisit	35 days (Sub-cycle 3 days)
Instruments		- Wide-swath and high-resolution optical imager (WISH, as a tentative) - Dual-frequencies Infrared sensor (hosted payload)
Ground Sampling Distance (GSD)		- Panchromatic band of WISH (Pa): 0.8 m - Multispectral band of WISH (Mu): 3.2 m (6 bands)
Swath width		70 km at nadir
Mass		Approx. 3 tons at launch
Size		5 m×16.5 m×3.6 m on orbit
Duty		10 mins / recurrent
Design life time		Over 7 years

Table 2 ALOS-3 WISH current specifications.

Items	Specifications
Panchromatic band (Pa)	
GSD, Swath width Wavelength MTF, SNR Quantization	0.8 m, 70 km at nadir 0.52-0.76 micrometers 0.1, 200 11 bits / pixel
Multispectral band (Mu)	
GSD, Swath width Wavelength (micrometers) MTF, SNR Quantization	3.2 m, 70 km at nadir Band 1: 0.40-0.45 (Coastal) Band 2: 0.45-0.50 (Blue) Band 3: 0.52-0.60 (Green) Band 4: 0.61-0.69 (Red) Band 5: 0.69-0.74 (RedEdge) Band 6: 0.76-0.89 (NIR) 0.2, 200 11 bits / pixel
Mission data rate	Approx. 4 Gbps (after onboard data compression: 1/4 (Pa), 1/3(Mu))
Mission data downlink	- Direct Transmission: Ka and X-band - *via.* the Optical Data Relay Satellite
Pointing	< 60 degrees by body pointing

3. ALOS-3 Observation Modes

Based on the satellite agility within 60 deg. pointing capability, five observation modes are prepared to meet various user requirements. The details are as follows.

3.1. Stripmap observation mode

ALOS-3 can normally perform observation covering 70 km in width and 4,000 km in along-track direction as the stripmap observation mode. To increase the acquisition frequency, the images will be taken by less than 25 deg. pointing angle in cross-track direction (GSD < 1m) when the satellite track is in oceans. Fig. 2 (a) shows an example of the stripmap observation.

3.2. Point observation mode

If the user has a certain ground point or an area of interest (AOI), ALOS-3 can observe there using pointing capability within 60 deg. This mode will be used for natural disaster monitoring, for example. Fig. 2 (b) shows an example of the observable coverages by 60 deg. pointing in cross-track direction.

3.3. Observation direction changing mode

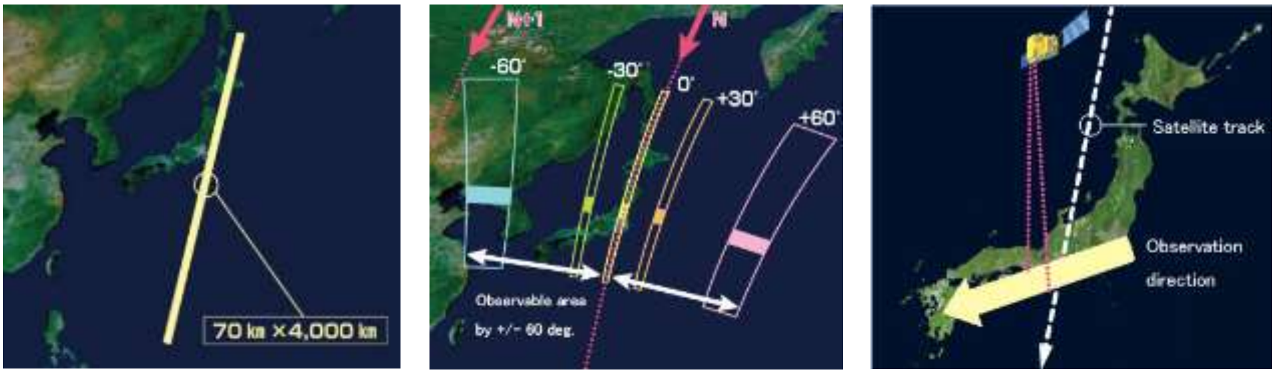
ALOS-3 can observe any given point by the pointing capability up to 60 deg. in all direction against the satellite nadir. This will be used when the large natural disaster happens. In the case of Japan, it can be activated within 24 hours after receiving the request. This will be used when the large natural disaster happens e.g. the expecting Nankai Trough large earthquake. Fig. 2 (c) shows an example of the observation direction changing mode to obtain information if the Nankai Trough large earthquake occurs.

3.4. Wide-area observation mode

This mode can cover in wide-ranging area of 200 km (in along-track direction) x 100 km (in cross-track direction) by satellite's single orbital passage. This will be also used when the large natural disaster happens.

3.5. Stereoscopic observation mode

To acquire stereo-pair images, two ways have been proposed: 1) in single orbital path, and 2) combining two stripmap observations by nadir view and backward view in neighboring path after three days that is sub-cycle revisit orbit. The way 1) will be however not sufficient base-to-height ratio (B/H) to derive terrain information. As the advantages of the way 2), that is possible to set suitable B/H, and can acquire images over large area. However, this will depend on weather conditions i.e. cloud covers, to success acquisition of the stereo images within short period as a disadvantage.



(a) Stripmap observation mode.

(b) Observable area coverages by point observation mode from some nadir path ("N" in this example).

(c) Observation direction changing mode.

Fig. 2 Example of ALOS-3 major observation modes.

4. Standard Product

Table 3 summarizes the definition of the standard product of ALOS-3. The image data will be provided in CEOS format or GeoTIFF format.

Table 3 The definition of ALOS-3 Standard product.

Level	Definition	Note
1A	Raw data	Frame subset and uncompressed data
1B1	Radiometric system corrected data from level 1A product	Separate to individual CCD unit. No map projection and resampling.
1B2	Radiometric and geometric system corrected data from level 1A product with Rational Polynomial Coefficient (RPC) file. Option R: Geo-referenced, G: Geo-coded	Scene-frame unit. Select: Map projection, Resampling, Pixel spacing
1C	Simple ortho-rectified image using existing Digital Elevation/Surface Model (DEM/DSM). Option R: Geo-referenced, G: Geo-coded	Scene-frame unit. Select: Map projection, Resampling, Pixel spacing

APPENDIX 6

OVERVIEW OF
THE ADVANCED LAND OBSERVING SATELLITE-4
(ALOS-4) MISSION

1. Introduction

The Advanced Land Observing Satellite-4 (ALOS-4) will observe the Earth's surface using its onboard the Phased Array type L-band Synthetic Aperture Radar-3 (PALSAR-3). The data will be utilized for monitoring disaster, forest, sea ice, infrastructure, and many other applications with the advantages of Synthetic Aperture Radar (SAR) such as all-weather and day-and-night observation capability. With further improved observation performance compared to the predecessor PALSAR-2 aboard ALOS-2, the satellite aims at achieving both high resolution and a broader observation swath.

ALOS-4 is equipped with a SAR antenna at the lower part of its body and with two solar array paddles at both sides, as shown in Figure 1. The observation data is transmitted to a ground station via. Ka-band data downlink with maximum rate of 3.6 Gbps. ALOS-4 will operate in the same orbit plane as ALOS-2. Table 1 shows system specifications of ALOS-4.

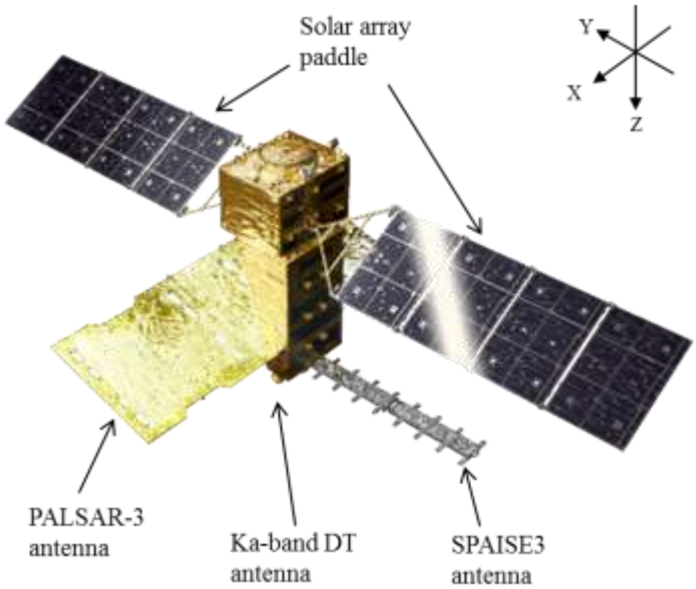


Fig. 1 ALOS-4 in-orbit configuration.

Table 1 ALOS-4 current specifications (under designed).

Mission Instruments	・ PALSAR-3 (Phased Array-type L-band Synthetic Aperture Radar-3) ・ SPAISE3 (SPace based AIS Experiment 3)
Orbit	・ Sun-synchronous sub-recurrent orbit ・ Altitude: 628 km ・ Inclination angle: 97.9 degree ・ Local sun time at descending: 12:00 ± 15 min. ・ Revisit time: 14 days (15-3/14 rev/day) (Same orbit as ALOS-2)
Mission lifetime	7 years
Satellite mass	Approx. 3 tons
Data downlink	3.6 Gbps/1.8 Gbps (Ka-band)

2. PALSAR-3 Specification

ALOS-4 carries the state-of-the-art L-band SAR called PALSAR-3. For the continuity of ALOS-2 data, PALSAR-3 will inherit the major function and performance (NESZ, S/A, etc.) of PALSAR-2 aboard ALOS-2. The observation swath width of PALSAR-3 will be expanded from PALSAR-2 without spoiling the spatial resolution by using the digital beam-forming (DBF) technique.

Fig. 2 and Table 2 show geometries and specifications of PALSAR-3, respectively. Spotlight and Stripmap modes will provide high resolution data. ScanSAR mode will observe wider area with 700 km swath width at the expense of spatial resolution. The observation repetition frequency of ALOS-4 will also be improved owing to the expanded swath width.

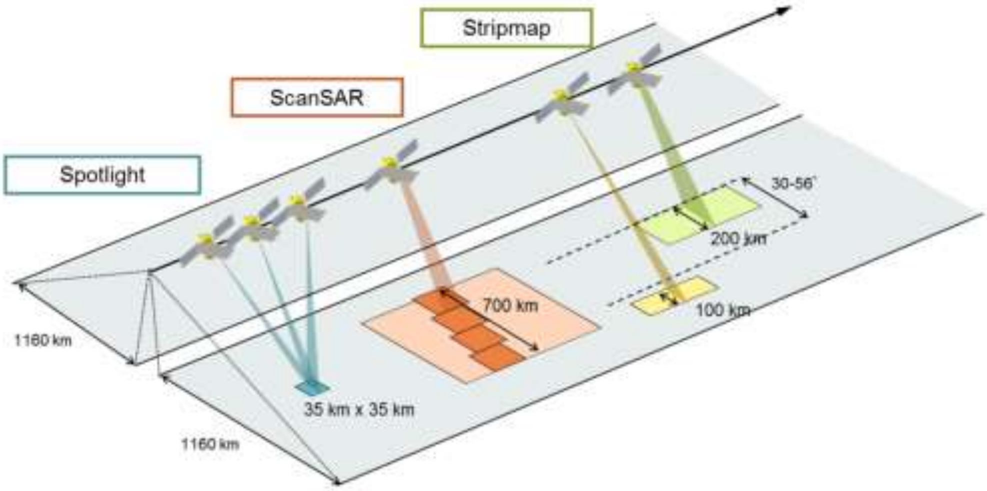


Fig. 2 Geometry of PALSAR-3 observation modes.

Table 2 PALSAR-3 observation modes and specifications.

Observation mode	Spotlight	Stripmap 3m		Stripmap 6m		Stripmap 10m		ScanSAR
SAR mode	Sliding-spotlight	Stripmap						ScanSAR
Center frequency (MHz)	1257.5	1257.5		1236.5 or 1257.5 or 1278.5				
Bandwidth (MHz)	84	84		42		28		28
Resolution (m)	3 x 1 (Rg x Az)	3		6		10		25 (1 look)
Swath width (km)	35 x 35 (Rg x Az)	200	100	200	100	200	100	700 (4 scan)
Polarization (HV basis)	1, 2	1, 2	1, 2, 4	1, 2	1, 2, 4	1, 2	1, 2, 4	1, 2
Incidence angle range (degree)	8-70	30-56	8-70	30-56	8-70	29-56	8-70	8-70
Split-band option (for ionospheric correction)	N/A	N/A	N/A	N/A	N/A	28+10 MHz	N/A	N/A

*Items in red color represent improvements or modifications from PALSAR-2

3. Standard Product

PALSAR-3 Standard Data Products (Level 1) are radiometrically and geometrically calibrated data and will be provided for ALOS-4 users. Table 3 shows the definitions of the Standard Data Products. In addition, higher-level data products including global mosaic and disaster map are planned to be released.

Table 3 PALSAR-3 standard data procucts.

Level	Definition
1.1	Range and azimuth compressed single-look complex (SLC) data on slant range
1.5	Geo-coded or geo-referenced amplitude image projected to map coordinate
2.1	Ortho-rectified amplitude image projected to map coordinate

APPENDIX 7

OVERVIEW OF
THE MULTI-FOOTPRINT OBSERVATION LIDAR AND IMAGER
(MOLI) MISSION

1. Introduction

Forest biomass is the dry weight of trees, and half of which is carbon weight, therefore it is frequently used as a unit to evaluate carbon stocks in forests. In addition, canopy height is one of the quantitative parameters of forest which can be measured relatively easily, and it is correlated with forest biomass. Meanwhile, in recent years, the necessity to measure forest carbon stocks has increased in relation to the climate change. In this context, demand for canopy height and forest biomass measurement technology is increasing significantly.

Also, the use of 3D maps has been increasing in various social fields recently. So far, JAXA has developed a global high-precision 3D map based on satellite images acquired by the ALOS PRISM. There is a demand for the use of 3D maps in forested areas. However, because ground surfaces are covered with forests, ground cannot be identified from images, and the Digital Terrain Model (DTM), which represents the height of a ground, does not satisfy the need for elevation accuracy in infrastructure construction, flood countermeasures, etc.

Among many satellite sensors, the Light Detection and Ranging (LiDAR) is the most accurate one capable of measuring those forest parameters and the height of ground. As shown in Figure 1, spaceborne LiDAR irradiates the ground surface with laser beam, and observes the waveform of reflected beam. Analyzing such waveform makes us possible to estimate the canopy height and the above-ground biomass (AGB) of forests. NASA's ICESat/GLAS, operated from 2003 to 2009, was the only spaceborne LiDAR to observe the Earth's surface so far. NASA will start to operate two spaceborne LiDAR missions i.e. ICESat-2/ATLAS and GEDI. In addition to these missions, the Multi-footprint Observation Lidar and Imager (MOLI) is expected to contribute to the semi-global forest observation.

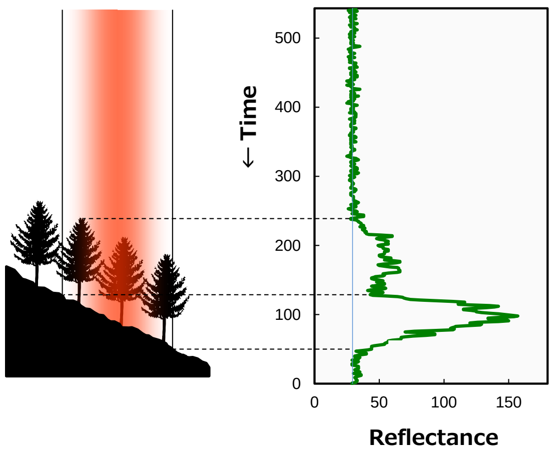


Figure 1 Schematic chart of spaceborne LiDAR observation.

2. Mission Objectives of MOLI

The objectives of MOLI are to provide accurate observation data of forest biomass over a wide area to reduce the uncertainty of the forest carbon budget in the carbon cycle process, to contribute as a monitoring tool for REDD+, one of the climate change countermeasures, and to improve the accuracy of 3D maps. Regarding the first objective, forests and other terrestrial ecosystems have the greatest uncertainty in the carbon cycle process, and accurate information on the distribution of forest biomass (i.e., carbon stocks) will contribute greatly to our understanding of this process. As for the second objective, the REDD+ scheme requires developing countries to have the capacity to accurately determine the carbon balance of their forests, and MOLI is expected to contribute to this. As for the last objective, highly accurate 3D maps are required for ground surfaces covered by forests, and MOLI is expected to create highly accurate DTMs using LiDAR data.

Furthermore, on the technical side, in the process of developing and operating MOLI, we will acquire spaceborne lidar technology, which will contribute to the realization of future spaceborne LiDAR missions.

3. Observation System

MOLI will be installed in the Exposed Facility of the Japanese Experiment Module (JEM) "Kibo" of the International Space Station (ISS). It has two sensors: LiDAR and imager. Table 1 shows the major specifications of each sensor. LiDAR, the main sensor, emits two laser beams to place the footprints continuously (Figure 2). When we estimate the canopy height or AGB from spaceborne LiDAR waveform, a pulse broadening effect by ground slope affects the estimation accuracy significantly. However, MOLI can calculate the ground slope angle by comparing measured values of ground elevation between adjacent footprints, and it can be used to correct the pulse broadening effect. This function can be expected to contribute to the improvement of the estimation accuracy of the canopy height and the above-ground biomass. In addition, the imager makes us possible to understand forest conditions around the footprint by shooting at the same time as LiDAR observation, although it has a narrow observation swath.

Table 1 Major characteristics of MOLI instruments.

Sensor	Parameter	Specification
LiDAR	Laser wavelength	1,064 nm
	Laser power	> 40 mJ
	Laser pulse frequency	150 Hz
	Laser pulse width	< 7 nsec
	Receive telescope aperture	450 mm (TBD)
	A/D sampling rate	500 Msps (height resolution = 30 cm)
	Measurement range	-50 m ～ +300 m above ground level (TBD)
	Footprint diameter	25 mΦ
Imager	Swath	1,000 m
	Ground resolution	5 m
	Band	Green, Red, Near Infrared (TBD)

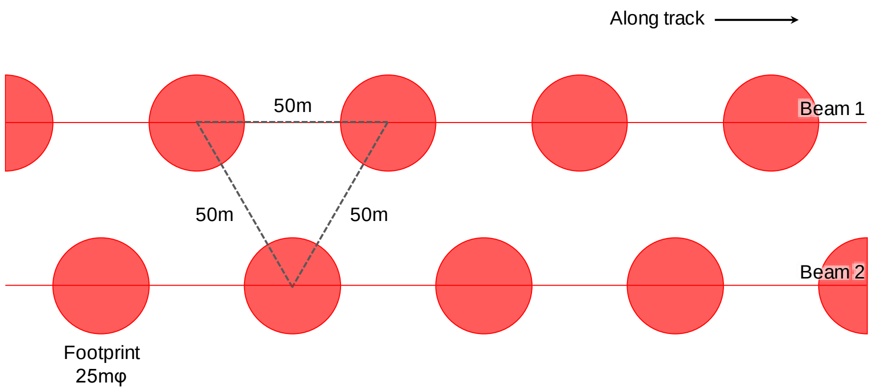


Figure 2 Distribution of LiDAR footprints of MOLI.

4. Products

MOLI has standard products of Level-1B and 2, and research products of Level-3 and 4 (Table 2). The L1B LiDAR product contains observed waveform with basic information i.e. geographical coordinates of footprint. The L2 product contains estimated values of the canopy height and AGB obtained as a result of waveform analysis for each footprint. L2 product also contains the height of ground for each footprint. Levels 3 and 4 products are the canopy height and AGB map created from combining LiDAR data with satellite image data. Regarding the image data, L3 uses images acquired by the MOLI imager, and L4 uses images acquired by other satellites i.e. ALOS-4/PALSAR-3 or GCOM-C/SGLI. Levels 3 and 4 products use L2 canopy height data and L2 AGB data as training data and validation data.

Table 2 MOLI products (under designed).

Level	Data source	Product	Specification
1B	LiDAR	Waveform data	-
	Imager	Ortho-rectified image	Alignment accuracy: < 2 pixels
2	LiDAR	Canopy height	Accuracy: < 3 m (@ canopy height < 15 m) / < 25% (@ canopy height > 15 m)
		Above-ground biomass (AGB)	Accuracy: < 20 Mg ha^{-1} (@ AGB < 100 Mg ha^{-1}) / < 25% (@ AGB > 100 Mg ha^{-1})
		Height of ground	Accuracy: < 3 m (@ slope angle < 30deg) / < 5m (@slope angle > 30deg)
3	LiDAR, Imager	Along-track canopy height map	Swath: 1,000 m, Ground resolution: < 100 m
		Along-track AGB map	
4	LiDAR, other satellite image	Large-scale canopy height map	Ground resolution: < 250 m
		Large-scale AGB map	

Note: target area is under 30° of ground slope.