APPENDIX 6

OVERVIEW OF THE MULTI-SENSOR 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.

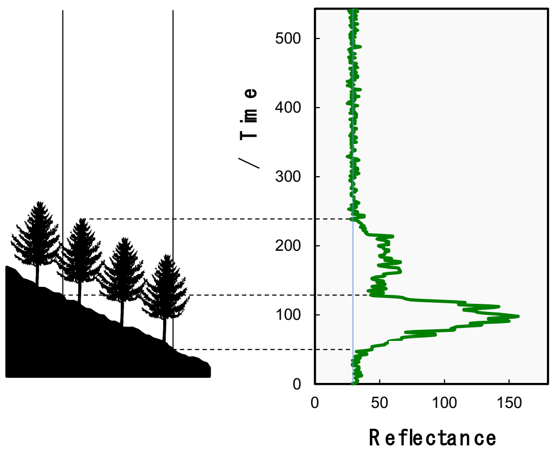

Figure 1 Schematic chart of spaceborne LiDAR observation.

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 on the Exposed Facility of the Japanese Experiment Module "Kibo" on the International Space Station (ISS.) As the name suggests, MOLI is equipped with two sensors, LiDAR and imager. Table 1 shows the main specifications of each sensor: LiDAR fires a laser 150 times per second nadir direction to observe a line just below the ISS at an interval of 50 meters. The imager will observe an area over 1 km swath centered on the LiDAR observation line at the same time. Using these images, we will be able to monitor changes in the growth conditions and seasonal variations of the forests around the LiDAR observation points.

Table 1 Major characteristics of MOLI instruments.

Sensor	Parameter	Specification
LiDAR	Laser wavelength	1,064 nm
	Laser power	about 40 mJ
	Laser pulse frequency	150 Hz
	Laser pulse width	< 7 nsec
	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, Pan (TBD)

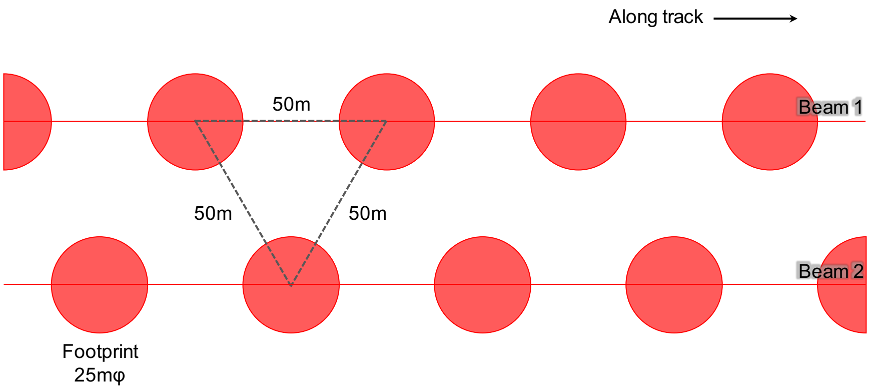

Figure 2 Distribution of LiDAR footprints of MOLI.

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	Swath: > 1,000 m,

			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,
		Along-track AGB map	Ground resolution: < 100 m
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.