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. Also, 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.

Among many satellite sensors, the Light Detection and Ranging (LiDAR) is the most accurate one capable of measuring those forest parameters. 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.

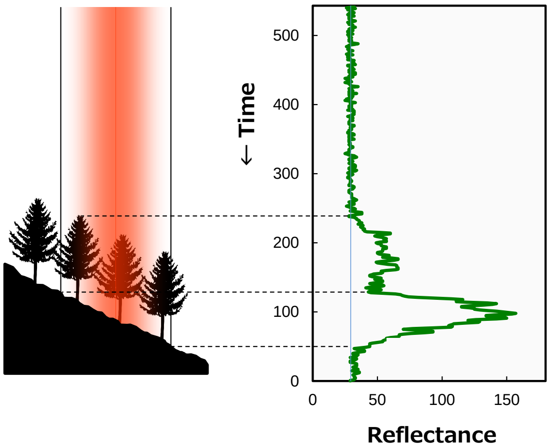

Figure 1 Schematic chart of spaceborne LiDAR observation.

2. Mission Objectives of MOLI

MOLI will provide accurate observation data of forest biomass on semi-global scale, and its objectives are to reduce the uncertainty of forest carbon budget in the carbon cycle process, and to contribute as a monitoring tool for the REDD+ scheme, which is one of measures against climate change. Regarding the former objective, terrestrial ecosystems (chiefly forests) have the largest uncertainty in the carbon cycle process, so accurate information of forest biomass (i.e., carbon stocks) distribution can greatly contribute to the progress of understanding it. Regarding the latter objective, the REDD+ scheme demands developing countries to accurately account forest carbon budget, so MOLI is expected to help them. Furthermore, a secondary objective is to acquire spaceborne laser technology in the process of development and operation of MOLI instrument, and to make it a preparation for future spaceborne LiDAR mission.

3. Observation System

MOLI will be installed in the Exposed Facility of the Japanese Experiment Module (JEM) "Kibo" of the International Space Station (ISS) around 2021. 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 ～ +4,000 m above ground level (TBD)
	Footprint diameter	25 mΦ
Imager	Swath	1,000 m
	Ground resolution	5 m
	Band	Green, Red, Near Infrared

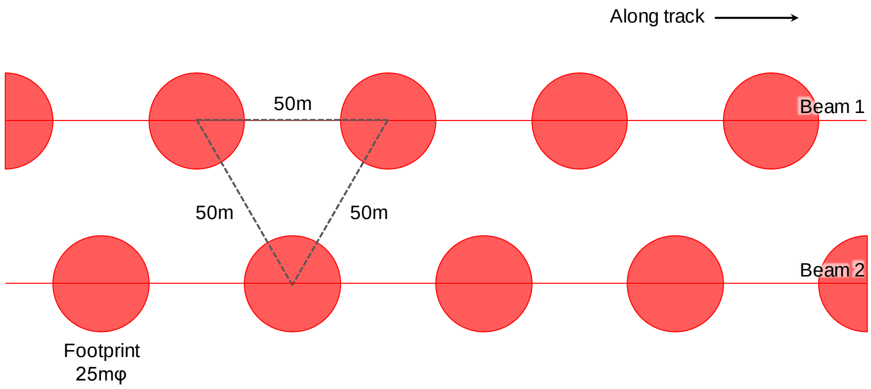

Figure 2 Distribution of LiDAR footprints of MOLI.

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. 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})
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.