Status of MOLI development

MOLI (Multi-footprint Observation Lidar and Imager)

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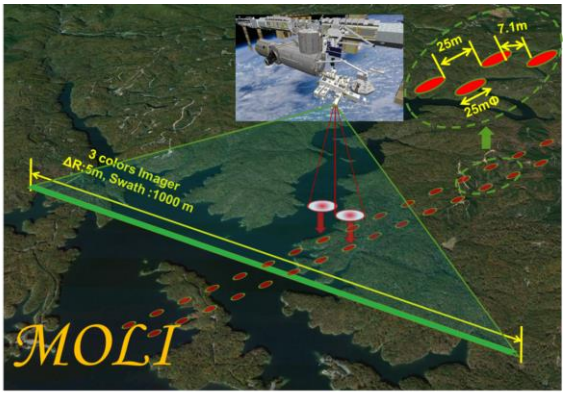
Outline of This Presentation

1. **Overview of MOLI**
2. **System Study**
3. **Trial test of Laser transmitter**
4. **Development Schedule**
5. **Observation Area of MOLI**
6. **Data Products**
7. **Tentative Cal/Val Plan**
8. **Summary**

Overview of MOLI

Overview of MOLI

- **MOLI** (**M**ulti-footprint **O**bservation **L**idar and **I**mager)
  - MOLI will be installed on ISS, Mass: 500kg, Power: 700W, Size: 1850x1000x800 mm
  - Orbit : ISS orbit
    - Non-synchronous
    - Inclination : 51.6 deg
      Altitude : 330～440 km
- **Sensors**
  - LIDAR
  - Imager
- **Objectives**
  - Improving knowledge for Above Ground Biomass
  - Acquisition of an Earth-observation lidar technologies



System Study

System Study -- System Requirements

Item	Mission Requirements	Requirements	How to realize
LIDAR SNR	To measure an accurate canopy height (in 3 m)	≧ 10	As shown later
Footprint diameter	To detect a top of canopy	25m	Beam divergence expands to 62.5 µrad by beam expander.
Sampling design	• To measure an accurate biomass • To estimate a slope angle of the ground surface	150Hz x 2 lines along track	Laser Pulse Repetition Frequency (PRF) is set to 150Hz. The number of beam is set to 2 beams per 1 pulse, and MOLI uses an array detector.
Imager	• To understand canopy location and vegetational parameters • For ground validation • To integrate LIDAR data and 2D data by another satellites	Spatial resolution: 5.0m (GSD) 3 bands (Green, Red, NIR)	MOLI will use a customized imager that is flight-proven.

SNR (1)

① Definition of SNR at MOLI

In this study, SNR is defined in Fig. 1.

S = average signal level in waveform extent

N = noise at no signal level (including background light noise)

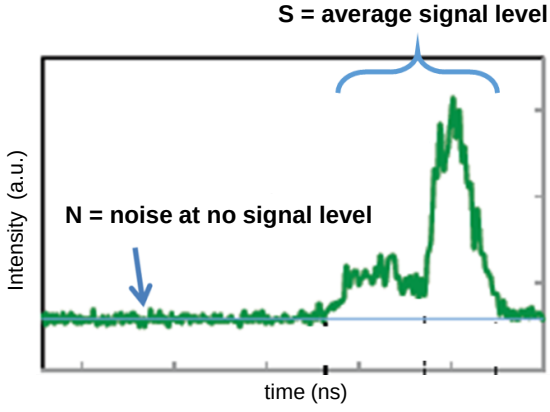


Fig. 1 Definition of SNR at MOLI

② Vegetation Model

- Canopy shape and the values : See Fig. 2
- Reflectance : 30%@1064nm
- Coverage : 1000 trees/1ha
  = about 50 trees/25mφ

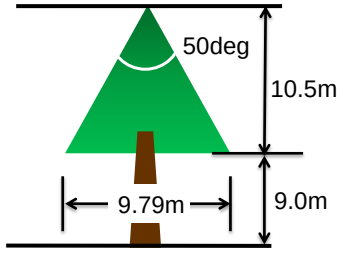


Fig.2 Vegetation model

SNR (2)

We calculate a received signal power using the following equation (1), and SNR using following equation (2).

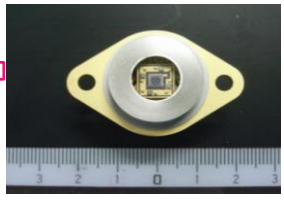
$$P_r = \frac{P_t \cdot K \cdot A_r \cdot {T_{atm}}^2(H)}{\tau \cdot H^2} \cdot \left\{ R_{VC}(H)\Delta C_{VC}(H) + R_{gd}\left(1 - C_{VC}(surface)\right) \right\} \quad \cdots(1)$$

P_r	Received signal power
P_t	Laser power
A_r	Aperture
K	Optical efficiency
T_{atm}	Atmospheric transmittance
τ	Pulse width
R_{vc}	Vegetation reflectance
C_{vc}	Coverage per 1footprint
ΔC_{vc}	Delta of coverage per height resolution
R_{gd}	Ground reflectance

$$SNR = \frac{M \cdot R_o \cdot P_r}{\sqrt{i_{n\_receiver}^2 \cdot B_w}} \cdots(2)$$

M	Gain
R_0	Detector sensitivity
P_r	Received signal power
$i_{n\_receiver}$	Total noise current
B_w	Bandwidth

We have conducted the trial test of the Si-APD array module with a low-noise TIA (right figure), and the results are used for calculating SNR.



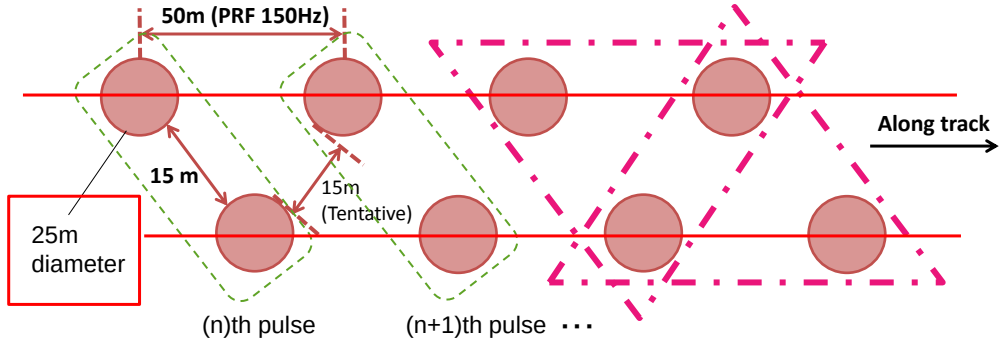
SNR (3)

Item	Symbol	Value	Unit	Note
Laser energy	Pt	20	mJ	Per 1 footprint
Aperture	Ar	0.28	m^2	0.65m in diameter
Optical efficiency	K	0.78	-	
Atmospheric transmittance	Tatm	0.89	-	@1064nm
Pulse width	τ	7	nsec	
Vegetation reflectance	Rvc	0.3	-	@1064nm wavelength
Delta of coverage per height resolution (Average)	ΔCvc	0.076	-	
Received signal power	Pr	31	nW	As a result of (1)
Gain	M	70	-	
Detector sensitivity	Ro	0.48	A/W	
Bandwidth	Bw	100	MHz	
Total noise current	i_n_receiver	4.5	pA/√Hz	Including background noise, detector noise, and thermal noise
SNR	SNR	17.2	-	Target : 10

We confirmed MOLI will achieve more than 10 on our vegetation model.

Sampling design and footprint diameter

- **To detect a top point of canopy**
  - We set the diameter of footprint to be 25 m.
- **To get a number of sample**
  - A number of sample is needed for measuring accurate biomass.
  - MOLI samples 2 lines along track.
    (MOLI creates 2 footprints by transmitting 2 laser beams.)
- **To estimate a slope angle of ground surface**
  - MOLI can estimate a slope angle of the ground surface using 3 footprints.



Main Specifications

Item	Value	Notes
Laser Wavelength	1064 nm	Nd:YAG Laser
Laser Energy	20 mJ	
Number of Laser	2	
Pulse Repetition Frequency	150 Hz	
Laser pulse width	7 nsec	
Laser Beam Divergence	62.5 μrad	
Diameter of Telescope	0.65 m	
Diameter of one receiver footprint	25 m	
Number of receiver element	2	array detector
Observation range	-50 m ～ 150 m	
Power	700 W	including imager
Weight	500 kg	including imager

Imager main Specifications

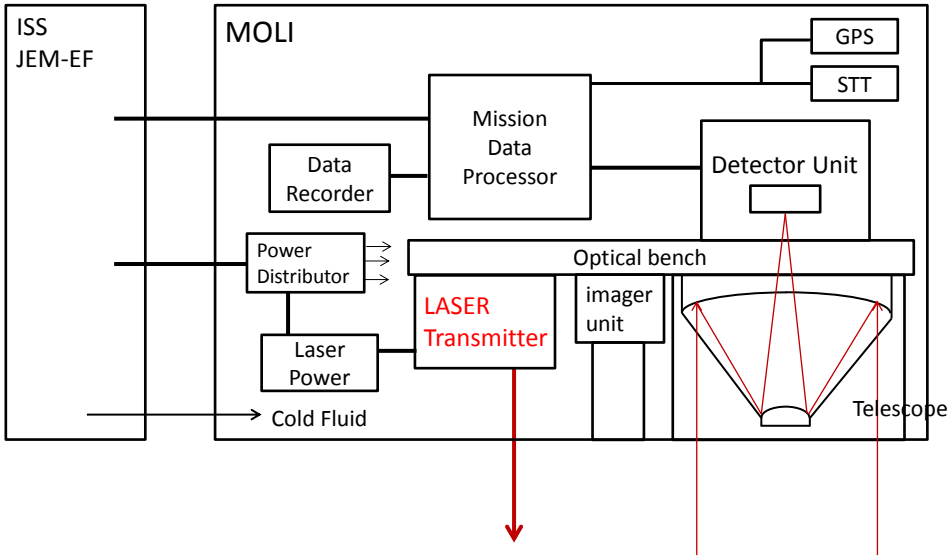
- **Main specifications**

  Number of Band : 3 bands（Green、Red、NIR）(Spectral range is shown in below)
  Spatial resolution : 5.0m
  Swath：1,000m (tentative)
  SNR ≧50 at each bands

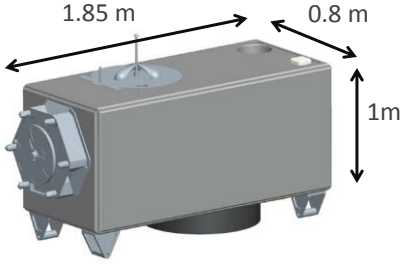
- **Tentative SNR**

Item	Value		
Band	G	R	NIR
Spectral range	550～630nm	640～720nm	740nm～880nm
Luminance	60% of the maximum value on the orbit		
Aperture	0.15m in diameter (tentative)		
Optical efficiency	0.7		
detector pixel size	12μm		
quantum efficiency	0.70	0.70	0.55
SNR	230	247	274

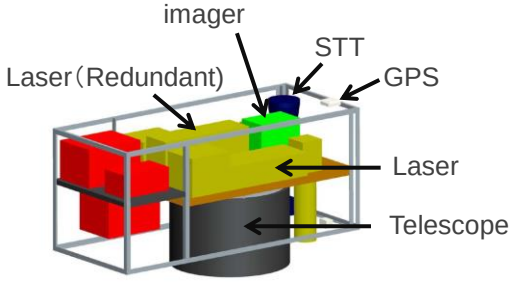
Schematic Diagram of MOLI System



Outlook of MOLI



an outlook



a perspective view

Outlook of MOLI

Trial test of Laser transmitter

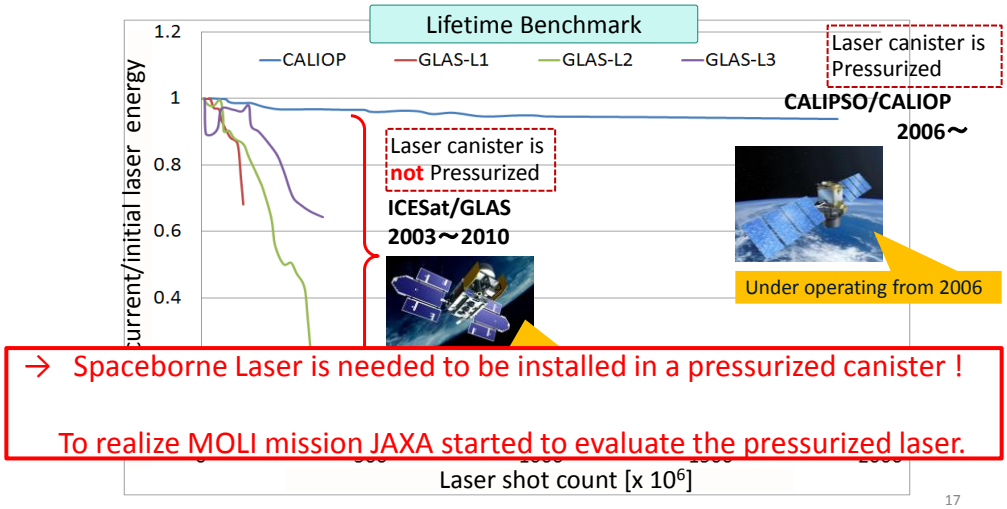
Required Parameters for MOLI Laser

Item	Value	Note
Laser energy	20mJ / 1 pulse (40mJ / 1 pulse is separated to 2 beams)	To achieve required SNR (≧10)
Laser PRF	150Hz	To get required number of samples
Pointing stability	< 100 μrad	To determine the geolocation of a laser footprint
Pressurized	About 1 atm.	To suppress the generation of contamination
Life	Over 1 year	target is 2 year
Vibration-proof	HTV launch environment	
Laser-incuded contamination	Pressurized around 1 atm	See the next slide

Problem on the laser induced contamination (LIC)

The LIC is one of the major issue to realize a space borne lidar.

The LIC reduces a damage threshold of the optical coatings, which results in limitation of the laser lifetime in space environment.



→ Spaceborne Laser is needed to be installed in a pressurized canister !

To realize MOLI mission JAXA started to evaluate the pressurized laser.

Objectives of pressurized Laser test

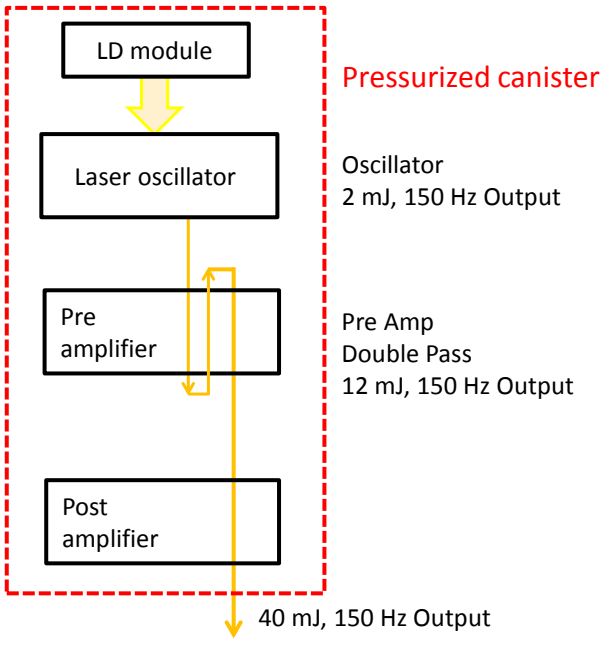
Focused point in evaluation of the pressurized laser

- Operation in Vacuum environment (Laser is set in vacuum chamber)
- Laser Energy and Power
  - 40mJ, 6W operation in vacuum condition
- Laser beam pointing stability
  - target: < 100 μrad
- Laser induced contamination
  - no rapid decrease
- Leak rate
  - Leak rate evaluation and an acquirement of data for a flight model
- Lifetime
  - Power down rate

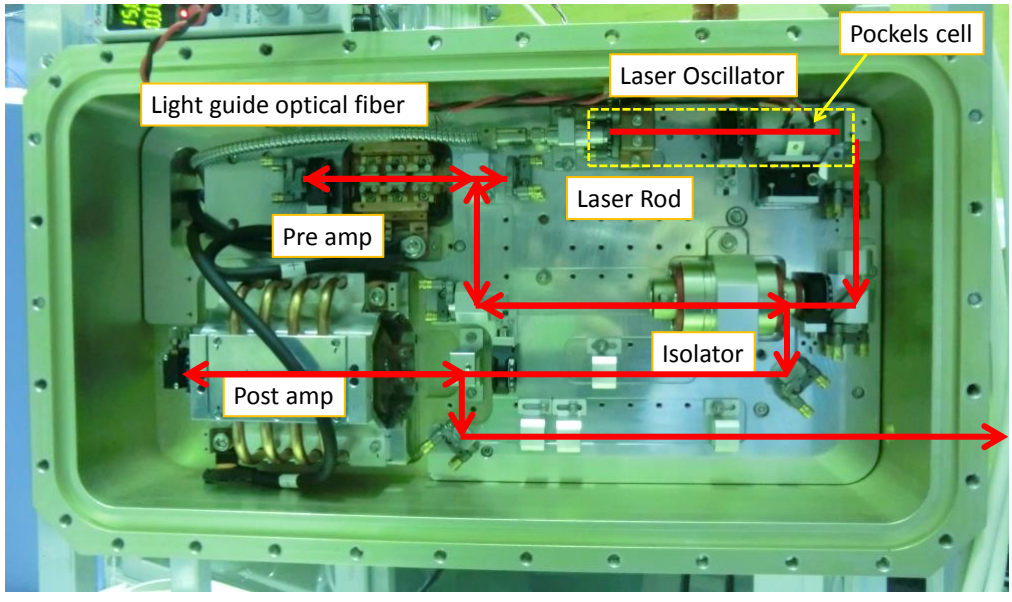
Specifications of a pressurized Laser

Item	Value	Note
wavelength	1064nm	LD pumped Nd:YAG laser
Laser energy	40mJ / 1pulse	This is separated to 2 beams
Laser PRF	150Hz	
pulse width	7～10ns	
Pointing stability	< 100 μrad	
Life	Over 1 year (target)	

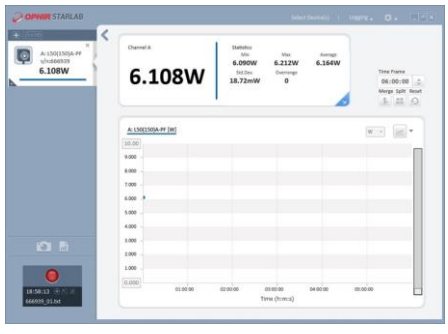
Schematic Diagram of trial test of Laser



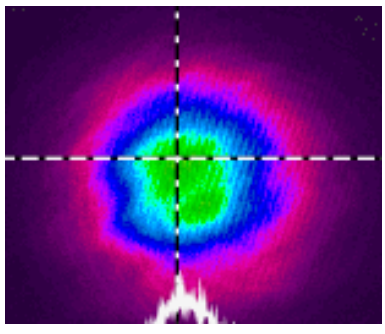
manufacture of Laser transmitter



Current result



6.11W at 150 Hz after 5 days operation
(about 40.7 mJ per one pulse)



Shape of the laser beam

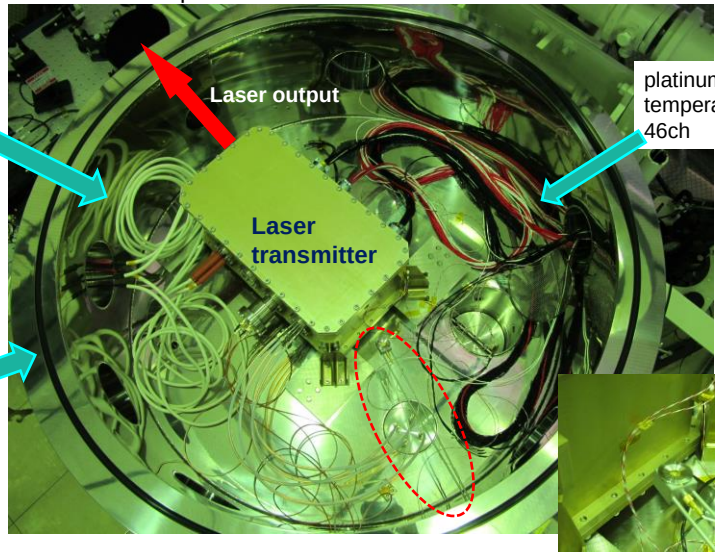
Pulse width: 6.4 ns
Beam pattern: Near Gaussian, $M^2 < 1.8$

trial test result summary

Item	Spec	test Result	status
wavelength	1064nm	1064nm	confirmed
Laser energy	40mJ / 1pulse	40.7mJ / 1pulse	confirmed
Laser PRF	150 Hz	150 Hz	confirmed
pulse width	7～10ns	6.4ns	confirmed
Pressurized	About 1 atm.	not conducted	will be confirmed in vacuum test
Pointing stability	< 100 µrad	not conducted	will be confirmed in vacuum test
Life	1 year (target)	We will conduct continuous test.	will be confirmed in vacuum test

Test Setup in vacuum chamber

Set up in the vacuum chamber



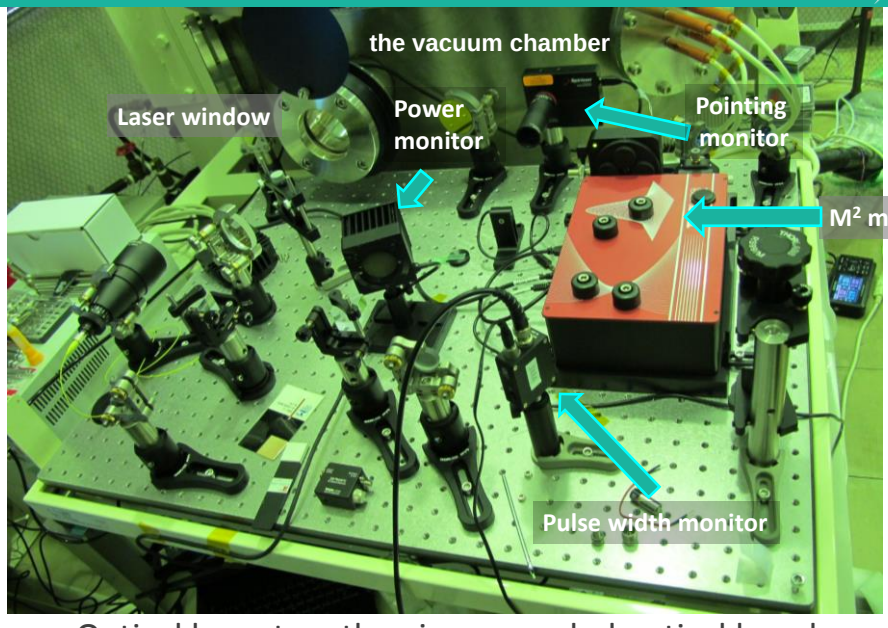
Current In/Out for Oscillator and Amplifier

platinum resistance temperature sensor 46ch

ϕ1m vacuum chamber

Contamination monitor (QCM)

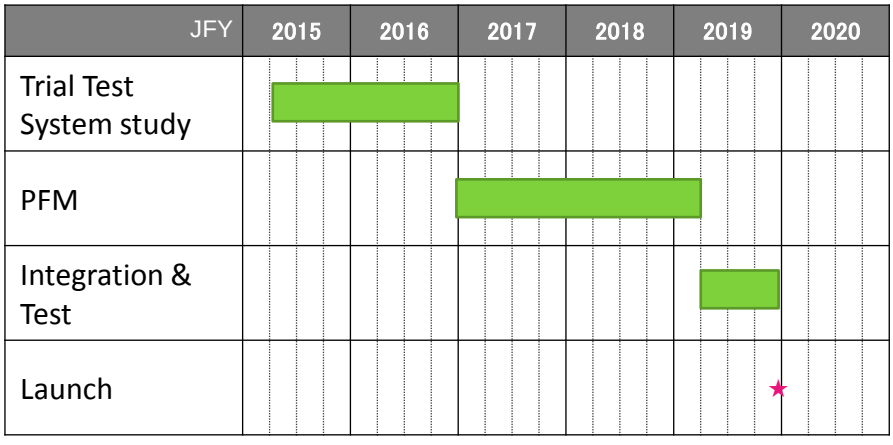
Setup of the performance test



Optical layout on the air-suspended optical bench

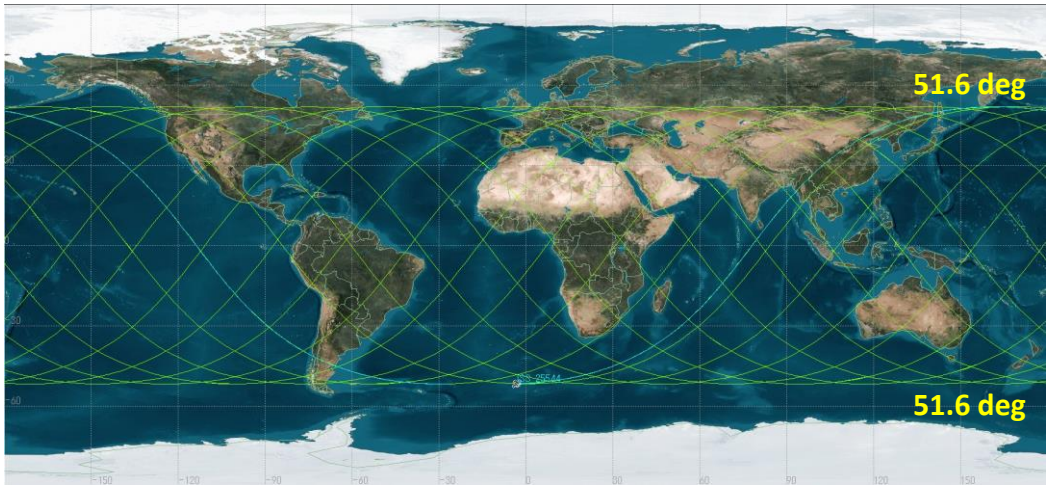
Development Schedule

Schedule (tentative)



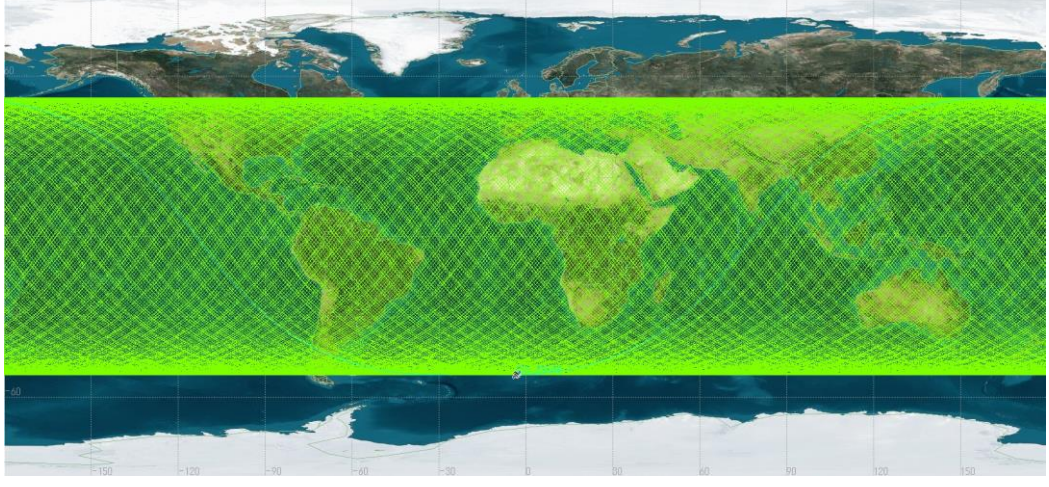
Observation Area of MOLI

MOLI observation area : one day for global

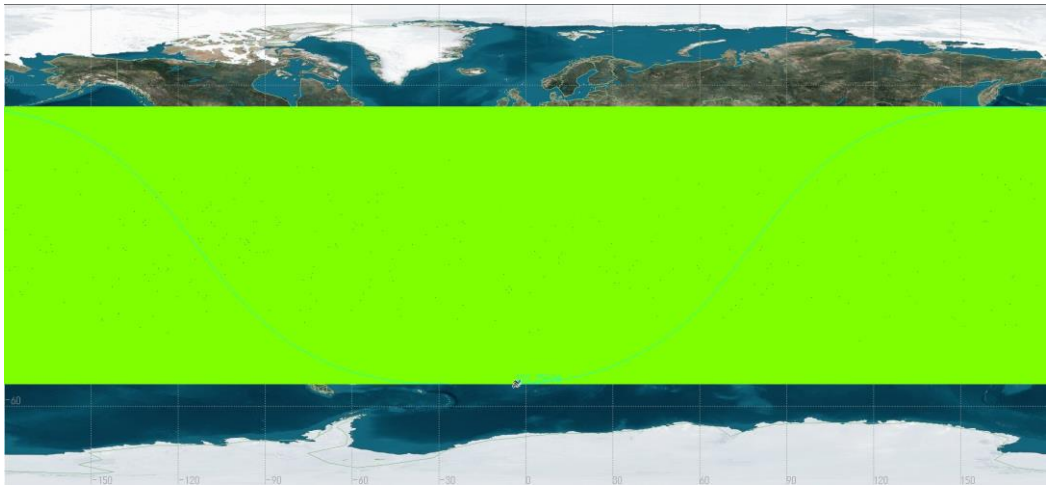


The inclination of ISS orbit is 51.6 deg.

MOLI observation area : one month for global

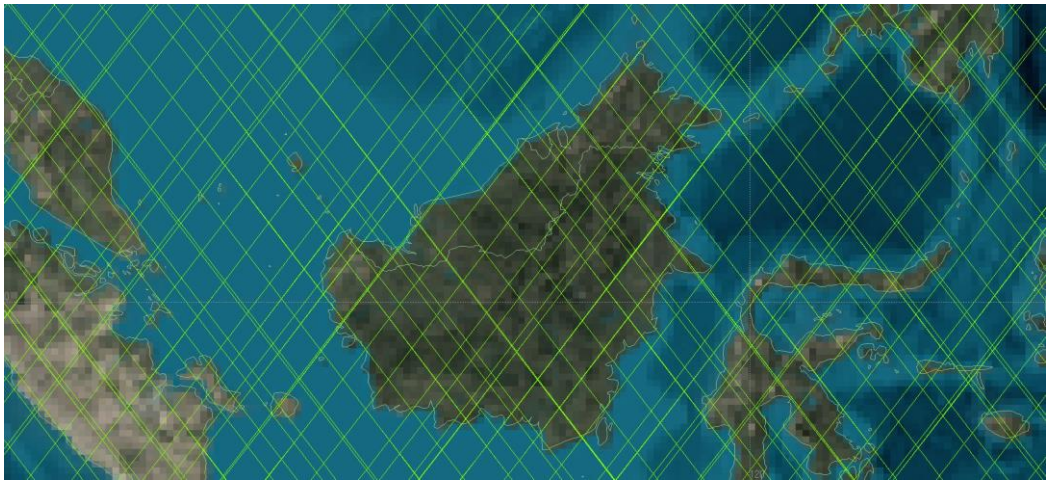


MOLI observation area : one year for global

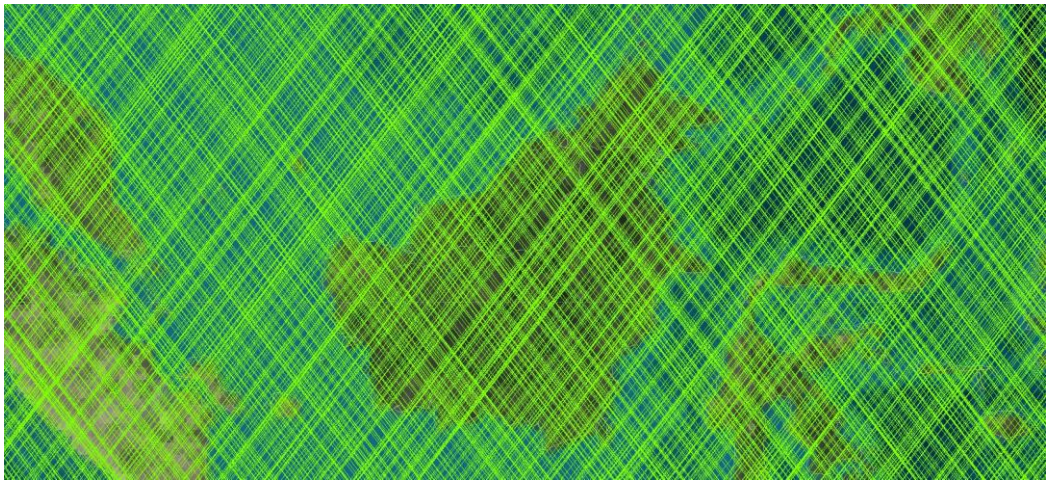


MOLI observation area : one day for particular area Borneo

MOLI observation area : one month for Borneo



MOLI observation area : one year for Borneo



The gap between the orbit is 3.5 km on the average.

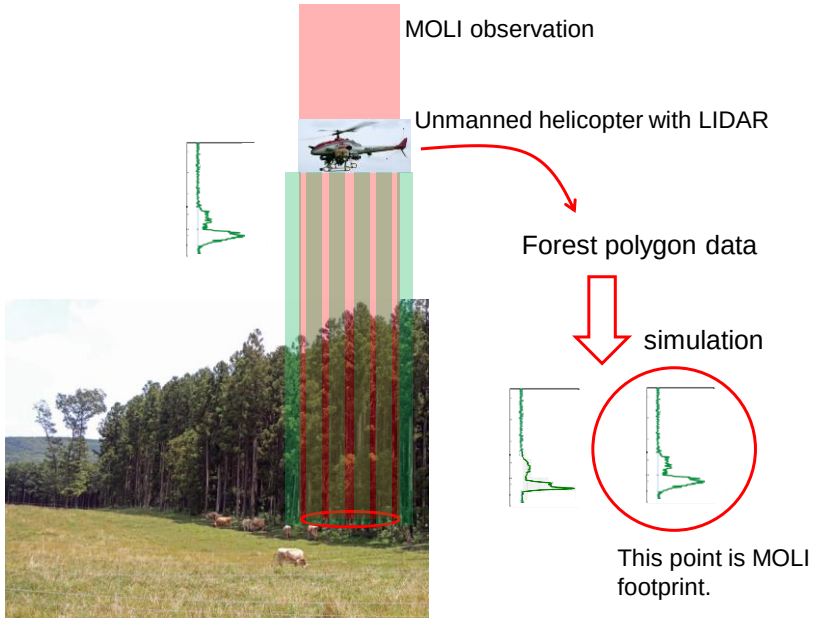
Data Products

Standard products of MOLI (tentative)

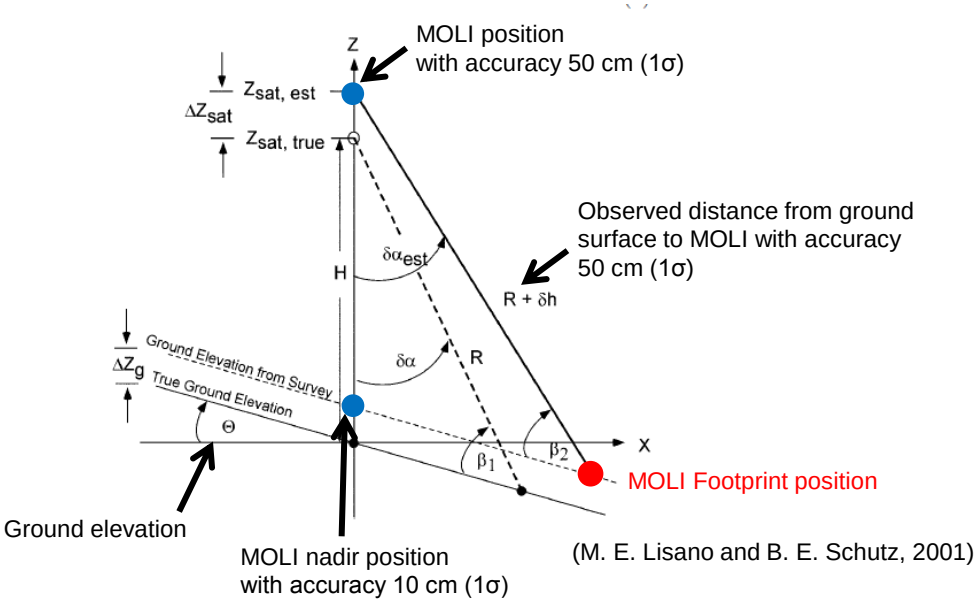
Product level	Product category	Products	Remark
L1	Lidar footprint products	Waveforms	including geolocation data
	Imager product (1km swath)	Image	geometrically corrected
L2	Lidar footprint products	Tree canopy heights	including geolocation data
		Forest biomass	including geolocation data
	Integrated products with Lidar and imager (1km swath)	Tree canopy heights	
		Forest biomass	
L3	Wall-to-Wall map products	Tree canopy height map	use for mainly global carbon cycle
		Forest biomass map	

Tentative Cal/Val Plan

Determination of observation point (pointing bias)



Determination of observation point (pointing bias) 2



(M. E. Lisano and B. E. Schutz, 2001)

Imager Cal/Val plan

Radiometric

- MOLI has no calibration system such as a lamp, solar diffused plate.
- The absolute radiometric calibration of MOLI imager will be carried out as cross-calibration with calibrated satellite images.

Geometric

- MOLI has Star Tracker (STT) and GPS. Precise observation point is determined using STT and GPS.
- Furthermore we use GCP (Ground Control Point) to geometrically correct an image.

Summary

Summary

- We performed system design of MOLI for accurately measuring canopy heights and confirmed system feasibility.
- We developed a trial test of a laser transmitter and had a good result (laser power and beam pattern) so far.
- Pressurized laser evaluation test is now progressing. Next, we will evaluate the performance under the vacuum environment.
- We plan to launch MOLI in 2019.