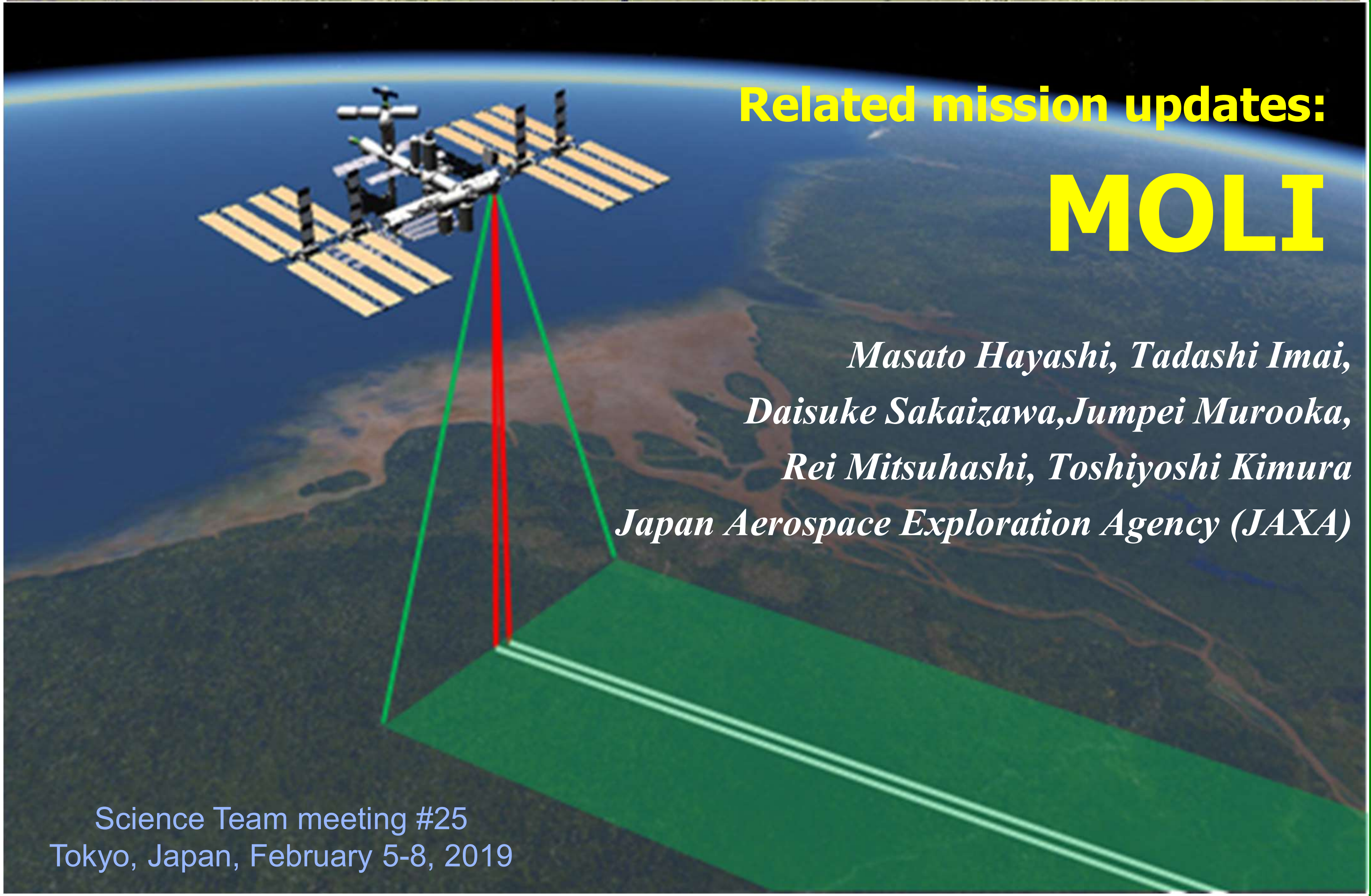
ALOS

K&C Initiative
An international science collaboration led by JAXA



Related mission updates:

MOLI

Masato Hayashi, Tadashi Imai,
Daisuke Sakaizawa,Jumpei Murooka,
Rei Mitsuhashi, Toshiyoshi Kimura
Japan Aerospace Exploration Agency (JAXA)

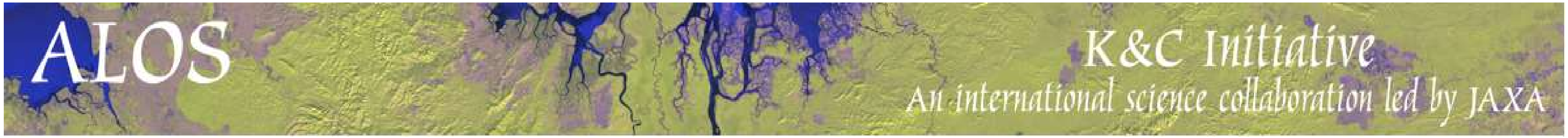
Science Team meeting #25
Tokyo, Japan, February 5-8, 2019

ALOS

K&C Initiative
An international science collaboration led by JAXA

- Introduction
- MOLI's feature
- Products of MOLI
- Preliminary results of airborne lidar experiment
- Summary

- **Introduction**
- MOLI's feature
- Products of MOLI
- Preliminary results of airborne lidar experiment
- Summary



Background

Global anthropogenic CO_2 budget (IPCC 2013, AR5)

	1750–2011 Cumulative PgC	1980–1989 PgC yr^{-1}	1990–1999 PgC yr^{-1}	2000–2009 PgC yr^{-1}	2002–2011 PgC yr^{-1}
Atmospheric increase[a]	240 ± 10[f]	3.4 ± 0.2	3.1 ± 0.2	4.0 ± 0.2	4.3 ± 0.2
Fossil fuel combustion and cement production[b]	375 ± 30[f]	5.5 ± 0.4	6.4 ± 0.5	7.8 ± 0.6	8.3 ± 0.7
Ocean-to-atmosphere flux[c]	–155 ± 30[f]	–2.0 ± 0.7	–2.2 ± 0.7	–2.3 ± 0.7	–2.4 ± 0.7
Land-to-atmosphere flux *Partitioned as follows*	30 ± 45[f]	–0.1 ± 0.8	–1.1 ± 0.9	–1.5 ± 0.9	–1.6 ± 1.0
Net land use change[d]	180 ± 80[f,g]	1.4 ± 0.8	1.5 ± 0.8	1.1 ± 0.8	0.9 ± 0.8
Residual land sink[e]	–160 ± 90[f]	–1.5 ± 1.1	–2.6 ± 1.2	–2.6 ± 1.2	–2.5 ± 1.3

Terrestrial carbon budget due to land use change and carbon absorption by forests is more uncertain than others. （Ciais et al., 2013 ）
It is important to estimate forest biomass precisely.

JAXA has begun studying the space vegetation LIDAR mission using the Multi-footprint Observation Lidar and Imager (MOLI).

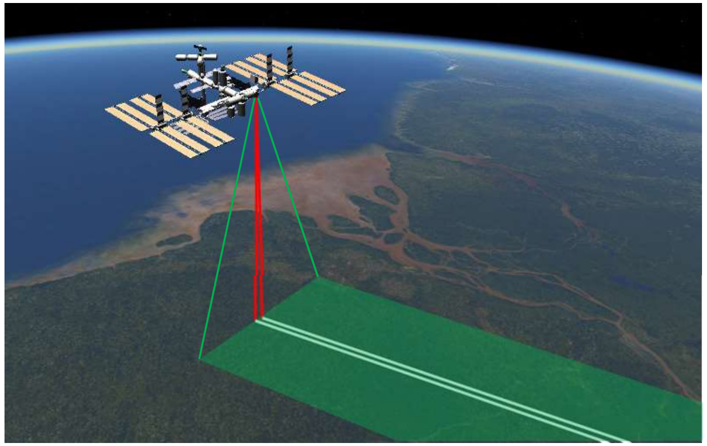
What's MOLI?

MOLI = 森

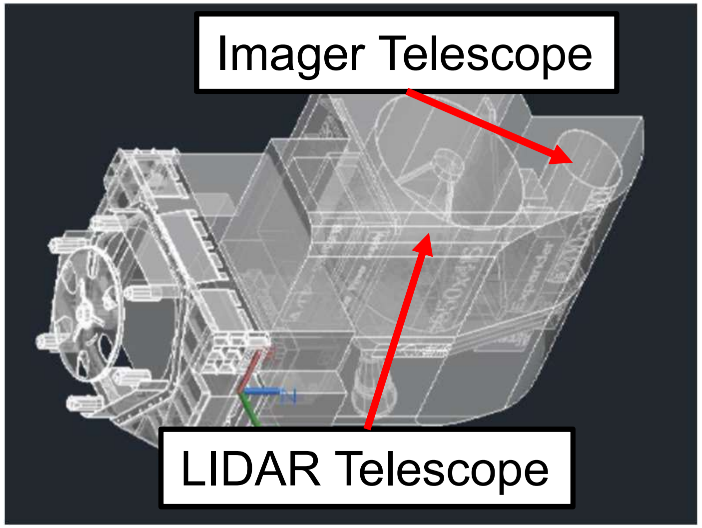
forest

MOLI (Multi-footprint Observation Lidar and Imager)

Items	Specifications
Mission instruments	◯LIDAR Laser wavelength/ 1064nm Number of beam / 2 beam (Split from one beam) Beam power/ 20mJ each Pulse width / less than 7ns Footprint radius / Φ25m ◯Imager Band / Green; 550-630nm Red; 630-740nm NIR; 740-880nm Spatial resolution / 5m Swath / 1km
Size	1605 × 640 × 830 [mm]
Mass	About 300 kg
Power	Less than 400W
Operation	Over 1year
Operational orbit	ISS orbit(Inclination : 51.6 deg) Non-synchronous at an altitude of 400km



Observation Image



Overview of MOLI

Introduction(4/4)

In-situ Measurement

Accurate but not homogenous globally

Needs tremendous resources (time, manpower)

Satellite Measurement(Optical Imager , SAR)

LANDSAT is powerful tool for its long-term record. However its measurement of ***Area.***

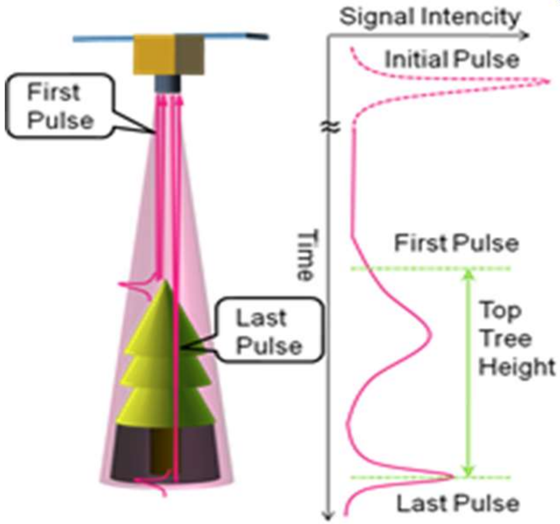
L band SAR can measure ***Volume,*** but saturation ~100t/ha [above-ground biomass]
(Luckman et.al. 1998)

Satellite LIDAR Measurement

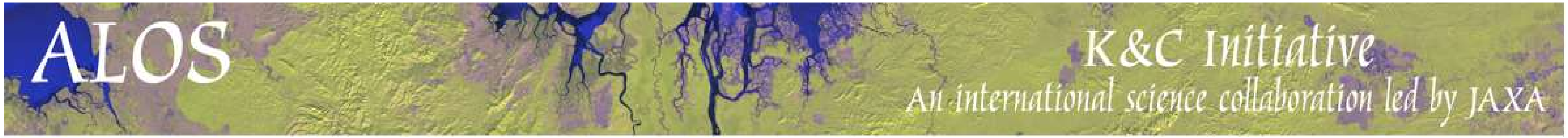
→Effective method of directly measuring tree height

Lidar is a sensor that transmits intense pulsed laser light to the ground, receives the reflected signal, and measures the distance from the round-trip delay time of the pulse.

The **biggest factor that affects** tree height and biomass estimation is the ***slope angle of the ground.*** (Rosette et al. 2008a, Hilbert & Schmullius 2012)

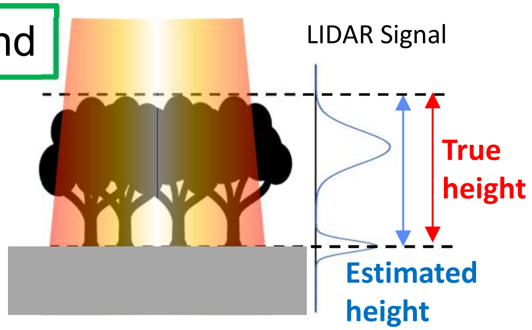


- Introduction
- **MOLI's feature**
- Products of MOLI
- Preliminary results of airborne lidar experiment
- Summary



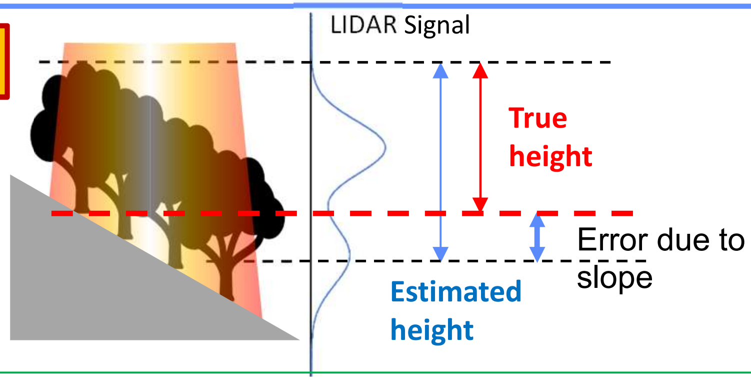
MOLI's feature → Improvement of canopy high observation by "Multi footprint"

flatland

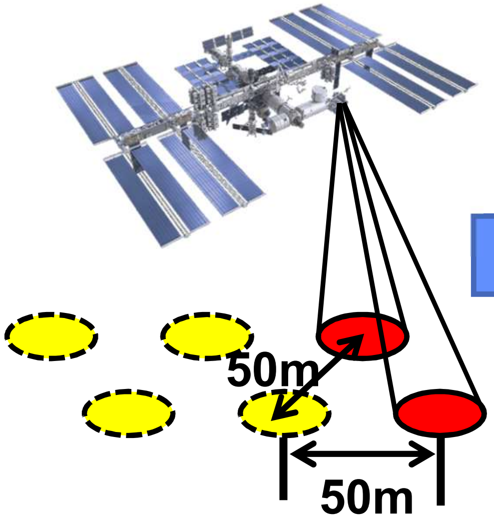


Canopy height
= Distance between Signal start and last pulse

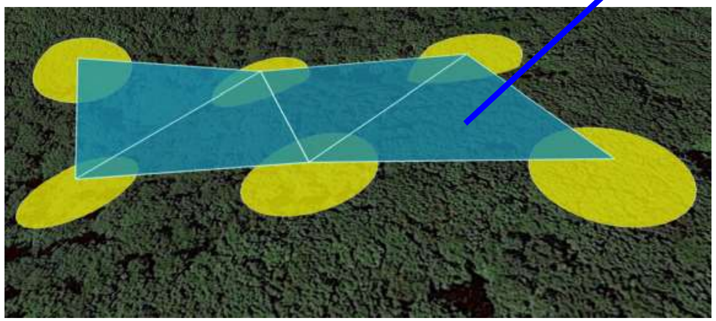
slope



Canopy height
= Distance between Signal start and last pulse
— Term for correcting error from slope



Two line laser

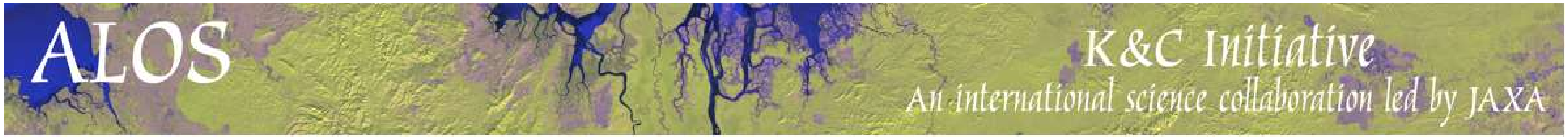


Estimate slope angle from altitude information of three footprints (observation points)

Expected effect by "Multi footprint"

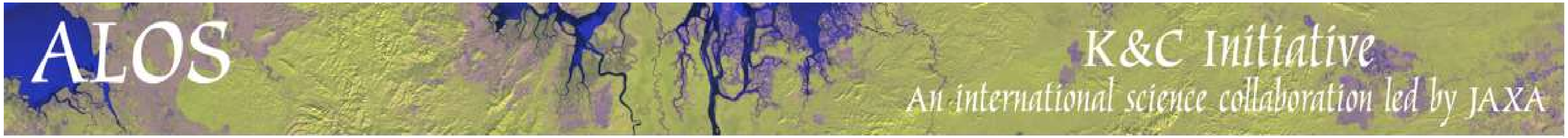
Before:
Correction using DEM data.

- Introduction
- MOLI's feature
- **Products of MOLI**
- Preliminary results of airborne lidar experiment
- Summary



Product level	Product category	Products	Remark
L1 (Standard)	Lidar footprint products	Waveforms (≧500Msps)	including geolocation data Footprint Position Accuracy ≦ 15m
	Imager product (1km swath)	Image （Red, Green, NIR）	geometrically corrected
L2 (Standard)	Lidar footprint products	Canopy heights	±3m(Canopy Height is under 15m) ±20% (Canopy Height is over 15m)
		Forest biomass	±25t/ha (Biomass density is under 100t/ha) ±25% (Biomass density is over 100t/ha)

※ Multi-footprint is expected to compensates each product up to 30 degrees of slope.



Product level	Product category	Products	Remark
L3 (Research)	Integrated products with Lidar and imager (1km swath)	Canopy heights	***Target*** 【Canopy heights】 ±~5m (Canopy Height is under 15m) ±~40% (Canopy Height is over 15m) 【Forest biomass】 ±~40t/ha (Biomass density is under 100t/ha) ±~40% (Biomass density is over 100t/ha)
		Forest biomass	
L4 (Research)	Wall-to-Wall map products (Integrated with GCOM-C/SGLI Data)	Canopy height map	
		Forest biomass map	

※ Multi-footprint is expected to compensates each product up to 30 degrees of slope.

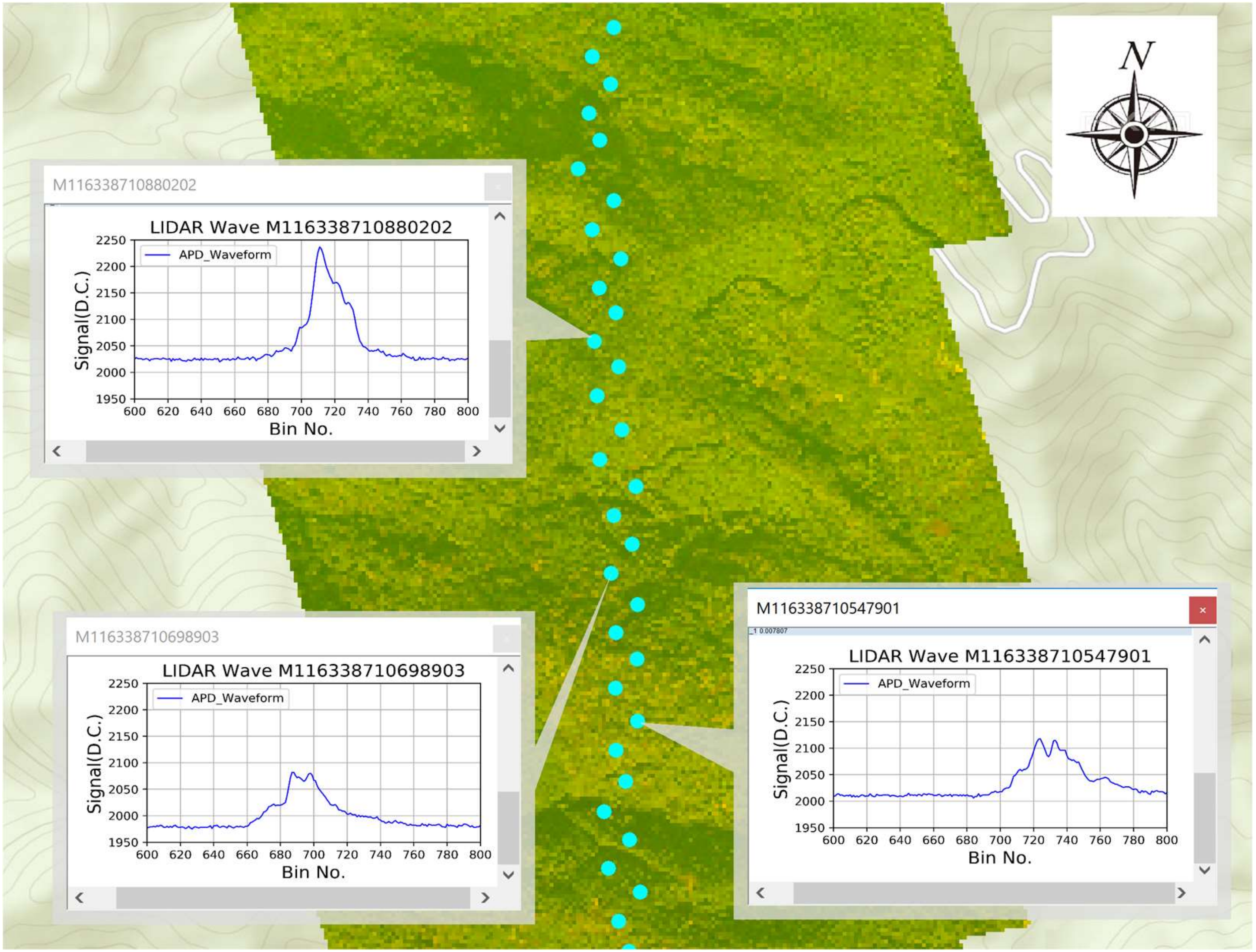


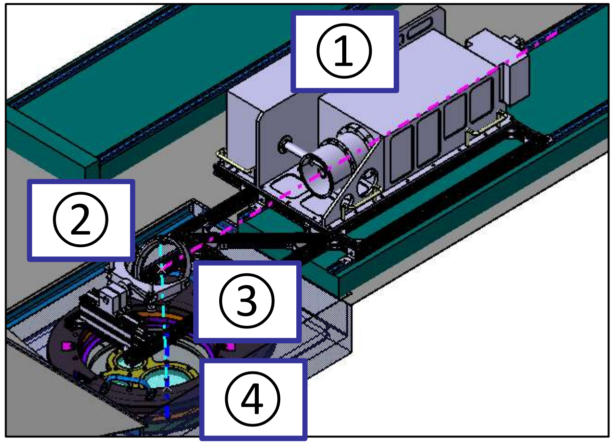
Image of L1 product at GIS software
(Using airborne lidar experiment at Ise forest)

- Introduction
- MOLI's feature
- Products of MOLI
- **Preliminary results of airborne lidar experiment**
- Summary

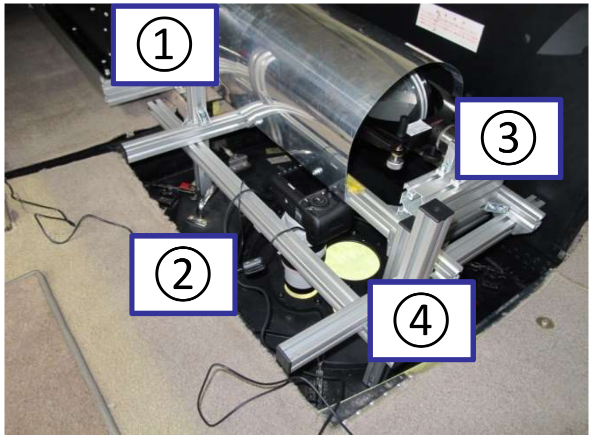
Test configuration

We installed a multi-foot print lidar system on aircraft(King Air 200T) with CCD camera (Canon EOS 5D Mark III).

Overview of King Air 200T



Lidar System(CAD model)



Lidar System(picture)

① l idar
②CCD camera
③reflection mirror
④window (AR Coating)

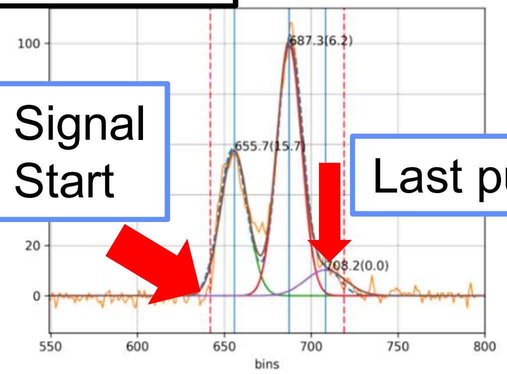
Preliminary results of airborne lidar experiment (2/5)

ALOS K&C Initiative — An international science collaboration led by JAXA

Data processing

LIDAR _waveform

Peak fitting



Signal Start

Last pulse

Calculate RH100

Correction by estimated slope

$$CanpyHeight = RH100 - 0.382D \cdot tan(slope)$$

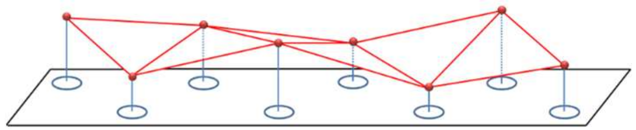
D = Footprint diameter

Calculate distance between airborne LIDAR to ground

POS_data

Calculate footprint geolocation position

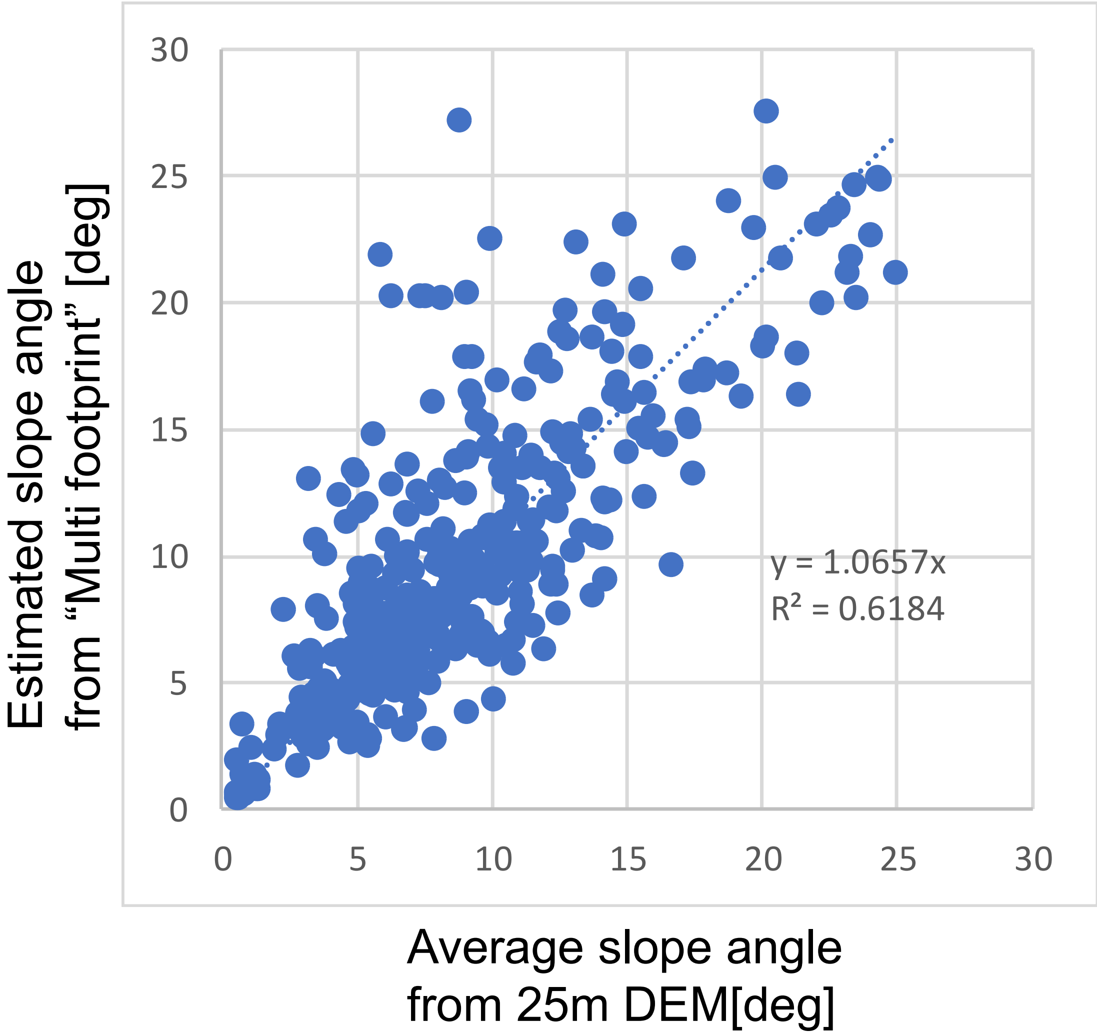
Calculate footprint slope



Estimated ground slope (Vertex normal method)

Preliminary results of airborne lidar experiment (3/5)

Estimated slope angle



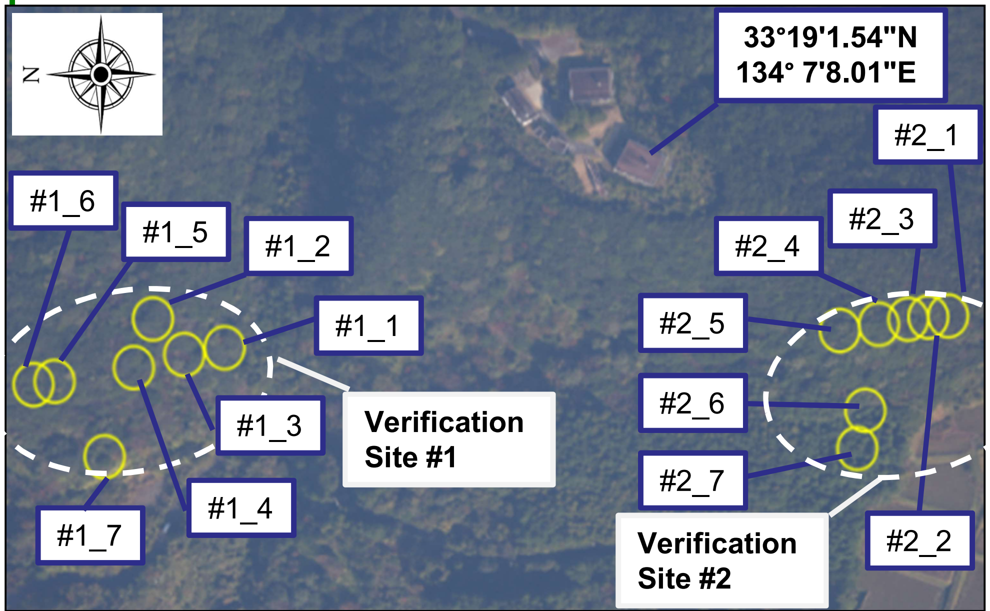
First, we compared estimated some footprint slope angle calculated by "Multi footprint" with DEM data.

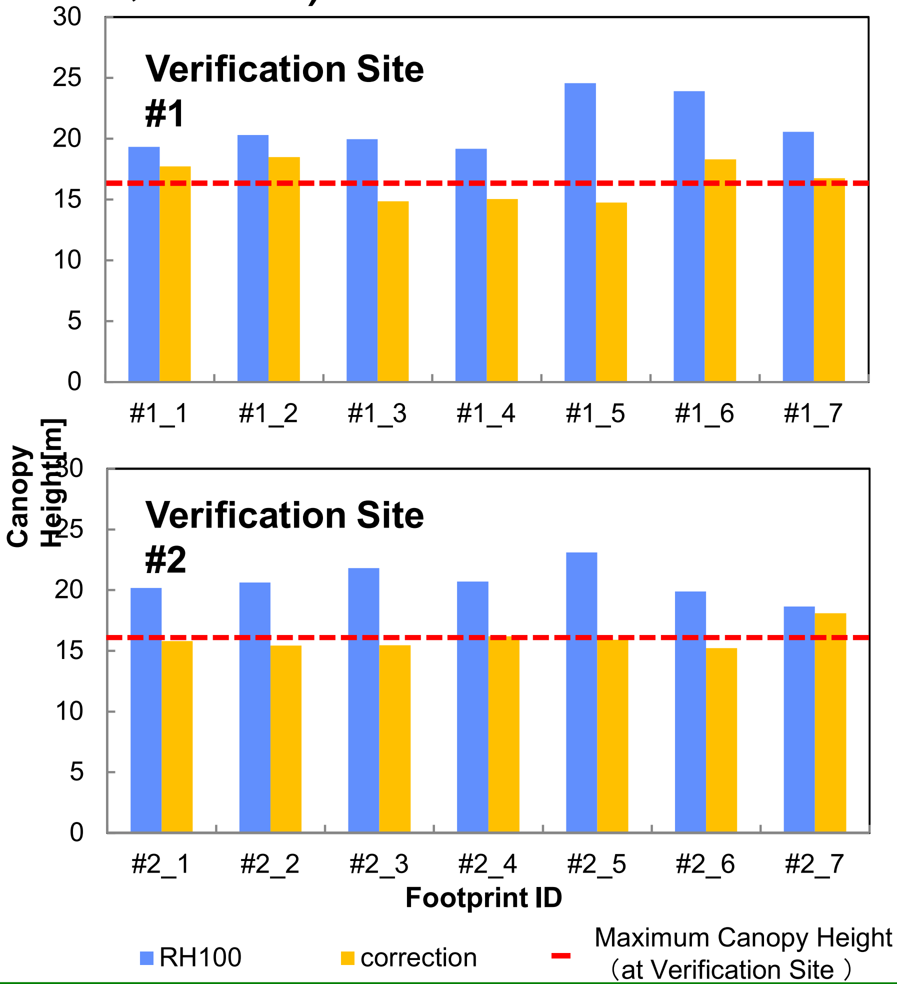
The DEM was resampled to 25 m square and calculated slope according to the footprint diameter of MOLI

From this result, we confirmed that the Multi footprint method can estimate roughly ground slope.

Verification (Muroto forest)

We validated the canopy height directly to verify the observation results at 3 sites. (Muroto, Gero)





Verification Site #1

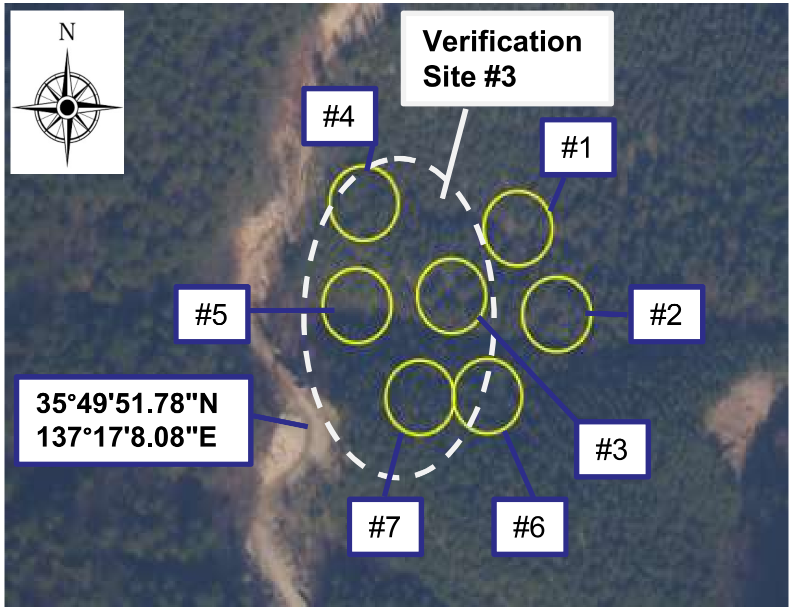
Error of before the correction : 4.94[m]
Error of after the correction : 1.54[m]

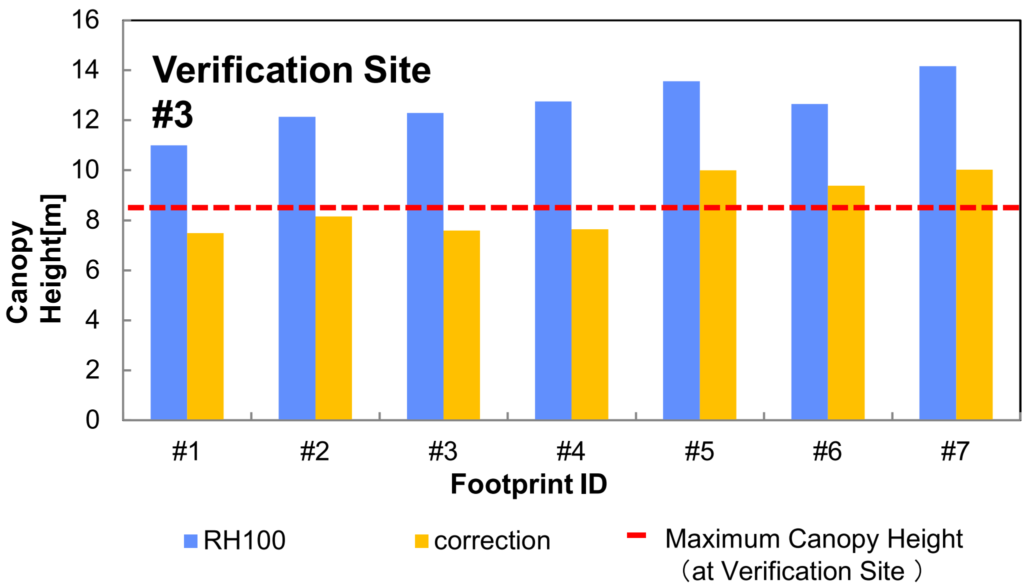
Verification Site #2

Error of before the correction : 4.30[m]
Error of after the correction : 1.08[m]

Preliminary results of airborne lidar experiment (5/5)

Verification (Gero forest)





Verification Site #3

Error of before the correction : 4.63[m]
Error of after the correction : 1.18[m]

These results show validity of the observation method using Multi-footprint for the mission requirement in 3 verification sites.

- Introduction
- MOLI's feature
- Products of MOLI
- System Design
- Preliminary results of airborne lidar experiment
- **Summary**

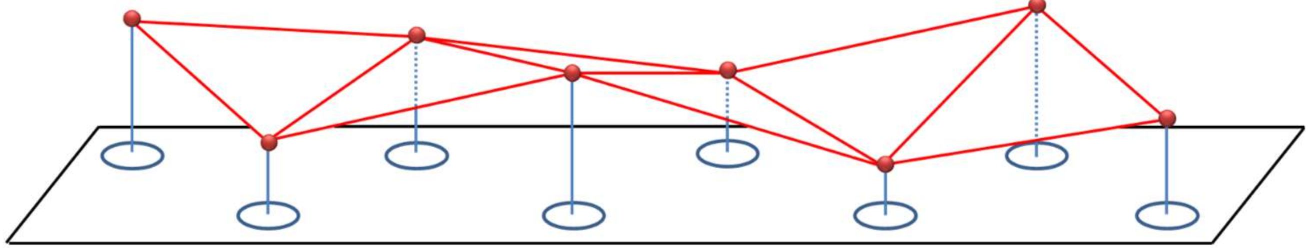
Summary

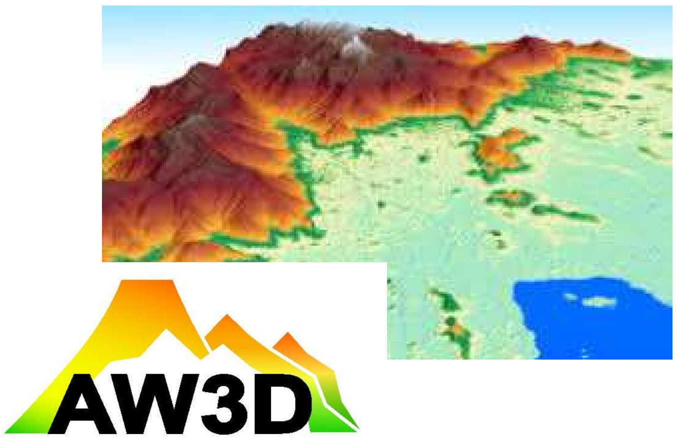
- MOLI Target launch : 2022~ (Now Phase A to B)
- JAXA/EORC called for MOLI's research proposals.
  (EO-RA2)

Future Work

- Method of slope angle calculation will improve.
- To evaluate the accuracy using Airborne Laser Scanning (ALS) data.
- To trial Integrated products with large footprint airborne Lidar data and imager(CCD camera) data.

Estimated ground slope result





Improve the estimated result?

Summary

- MOLI Target launch : 2022~ (Now Phase A to B)
- JAXA/EORC called for MOLI's research proposals.

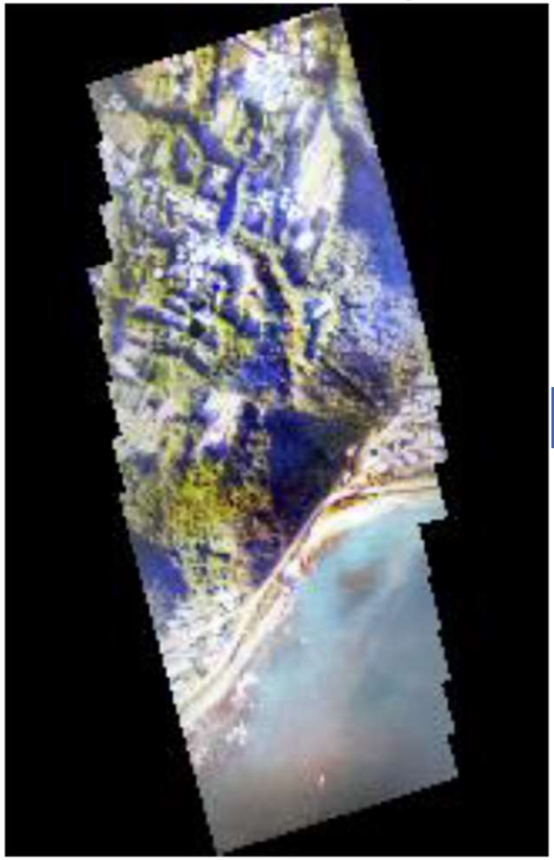
  (EO-RA2)

Future Work

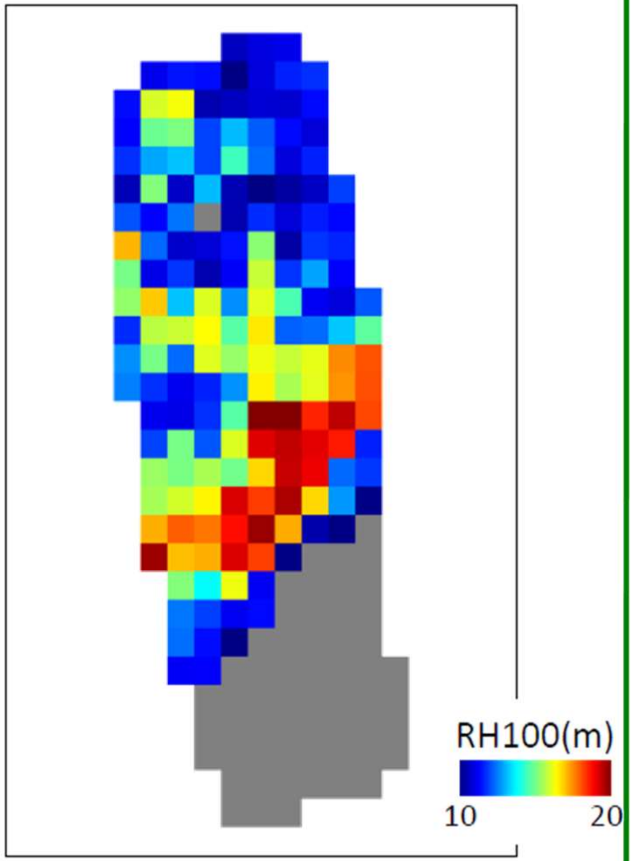
- Method of slope angle calculation will improve.
- To evaluate the accuracy using Airborne Laser Scanning (ALS) data.
- To trial Integrated products with large footprint airborne Lidar data and imager(CCD camera) data.

Prototype MOLI L3 product to airborne lidar experiment (Algorithm under development)

Raw CCD camera data
Spatial resolution ~10cm



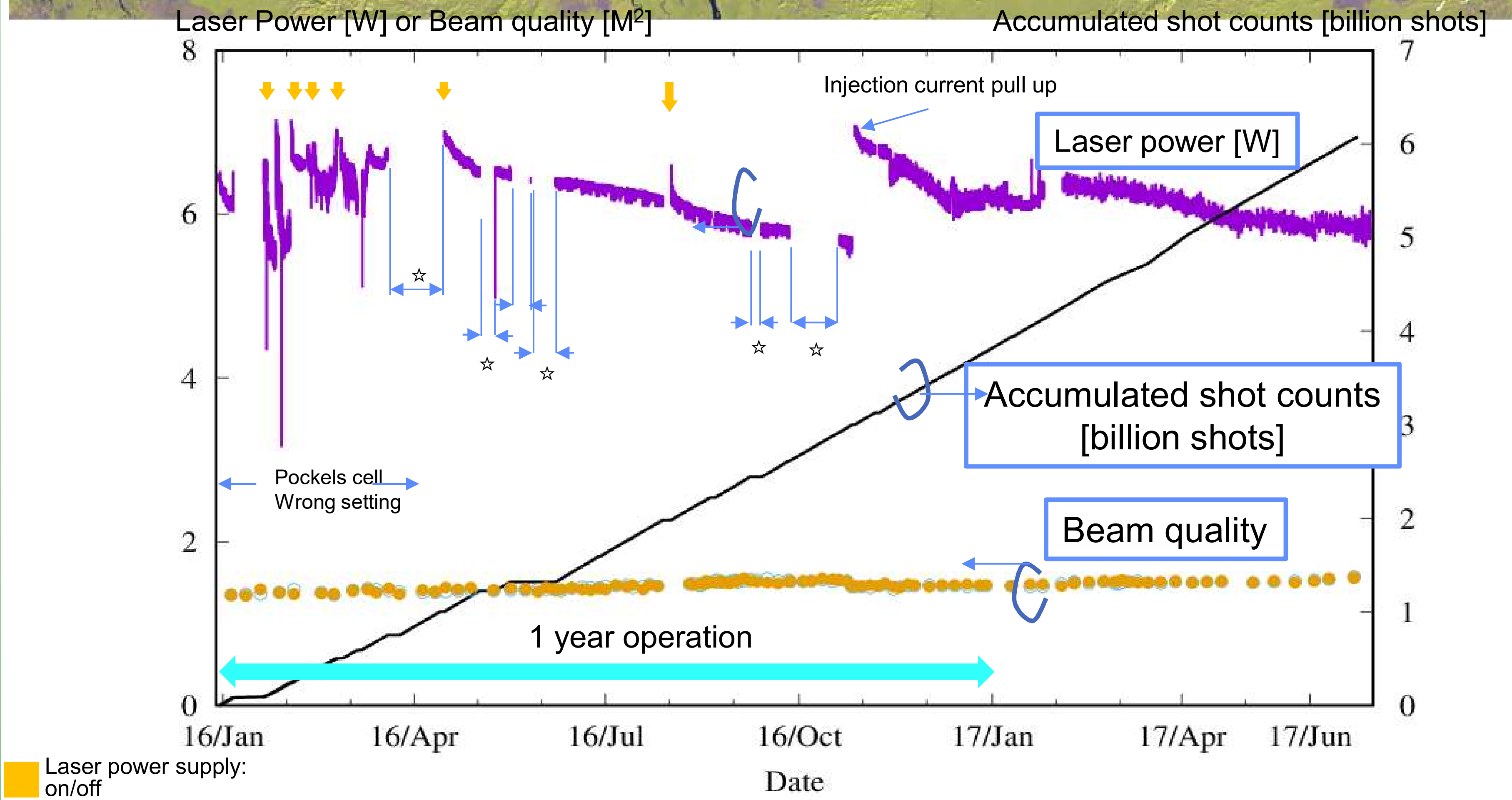
Adjust to MOLI Imager resolution(5m) and Smoothing local contrast



Integrated products with Lidar and imager data (40m mesh, RH 100)

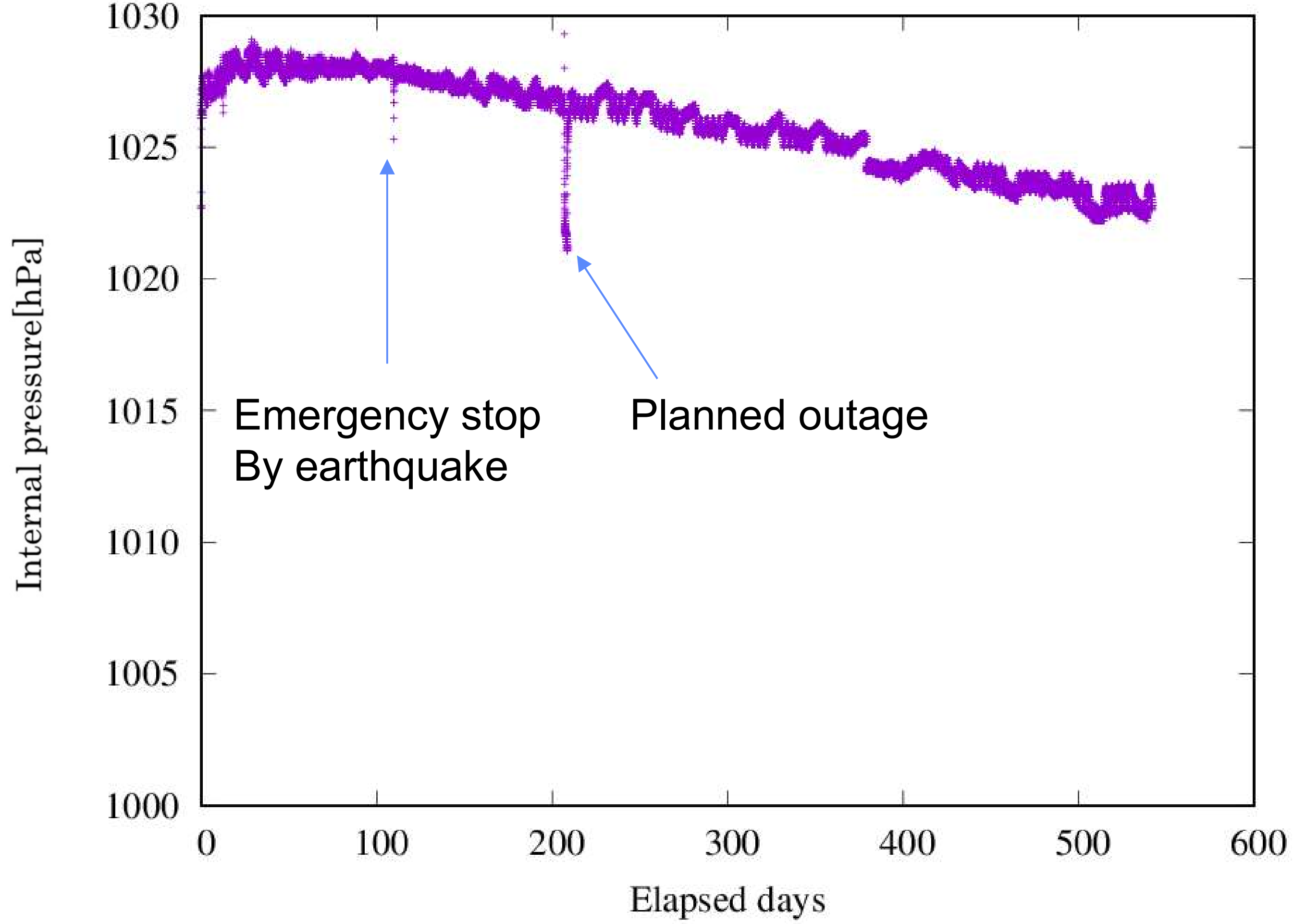
Thank you so much for your kind attention

Appendix



Space borne Laser is needed to be installed in a pressurized canister to prevent LIC.

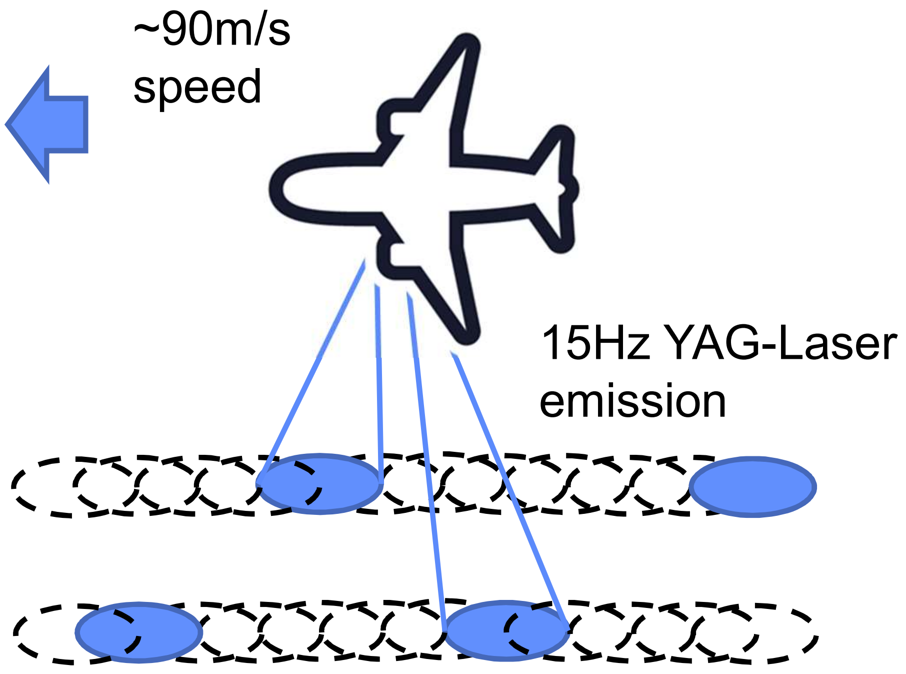
We have conducted trial test of Laser in vacuum and achieve more than one year operation of laser in vacuum condition.



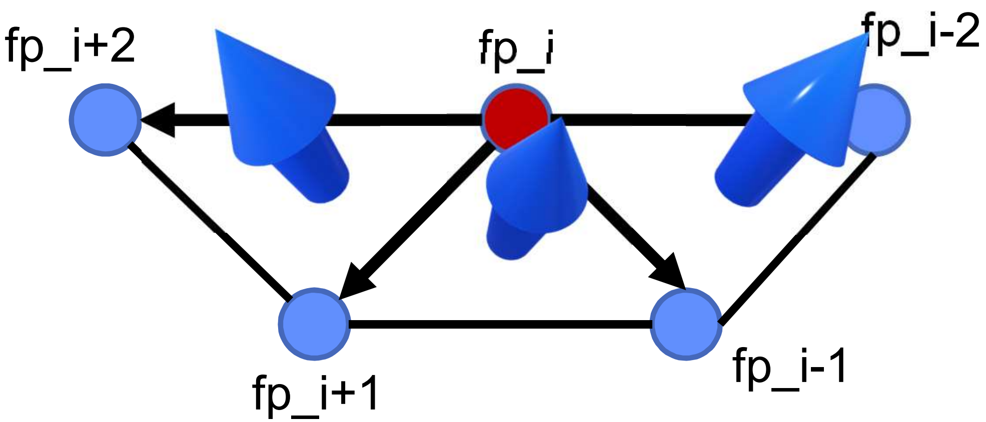
Pressurized canister keeps internal pressure less than 1% decrease

No leak observed during test periods

Preliminary results of airborne lidar experiment



In order to simulate MOLI sampling design, we selected the necessary analyzed data from footprint data overlapped because of relationship between airplane speed and laser Repetition frequency.



Calculate slope from vector normalized by adding all normals of triangle made of “Multi footprint”.

Slope correction for GLAS data (Ver. 2)

The laser intensity is shown as follows

$A_0 \exp(-\alpha r^2)$ Where r is distance from the center of footprint

The half of correction term is calculated as follows:

where $R = \frac{1}{2} D_f$

$$\bar{h} = \frac{\int_0^R \int_0^{\frac{\pi}{2}} A_0 e^{-\alpha r^2} \cdot r \cdot \cos\phi \cdot \tan\theta \cdot r \cdot d\phi dr}{\int_0^R \int_0^{\frac{\pi}{2}} A_0 e^{-\alpha r^2} \cdot r \cdot d\phi dr}$$

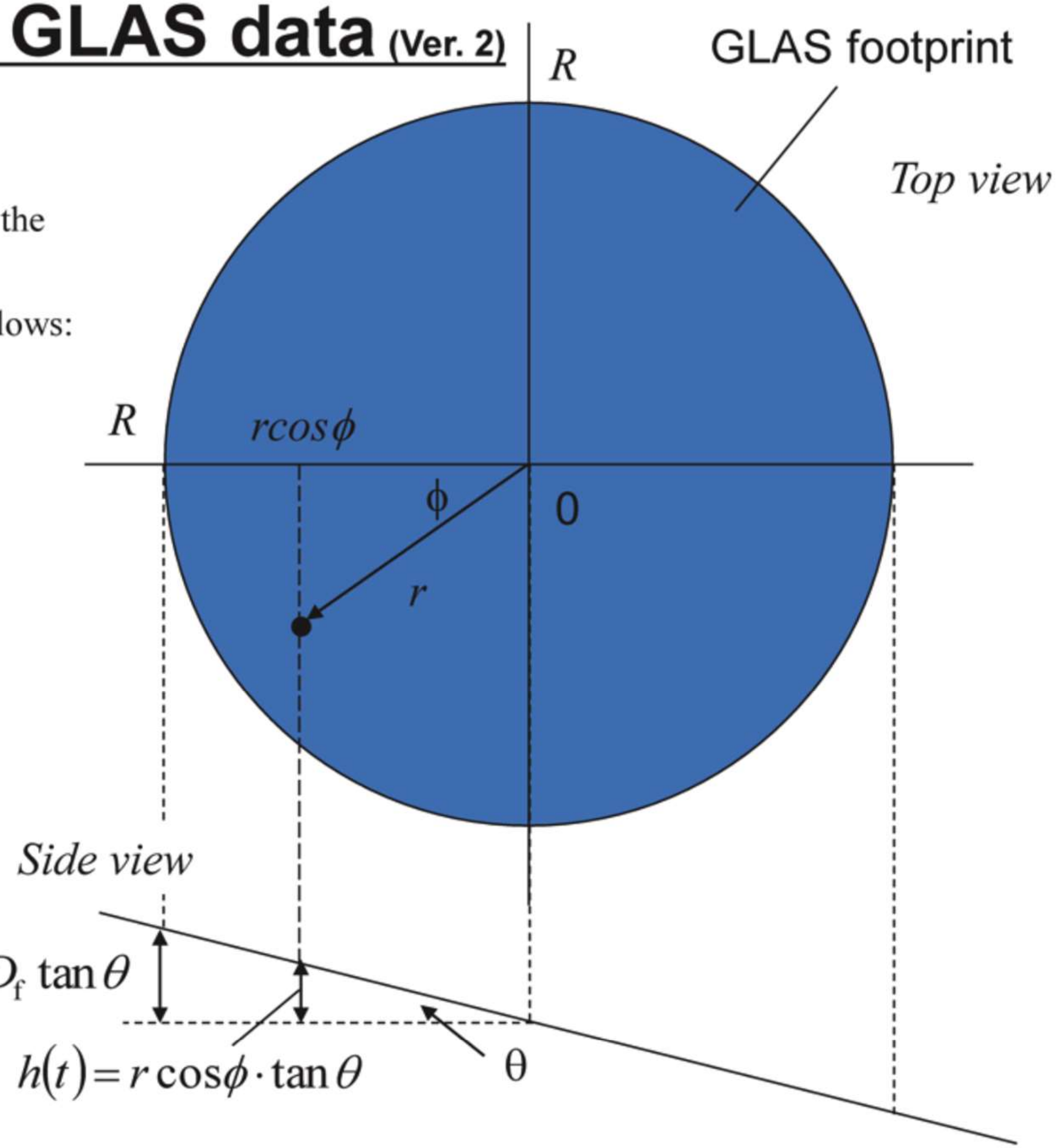
$$= \frac{A_0 \cdot \tan\theta \int_0^R \int_0^{\frac{\pi}{2}} e^{-\alpha r^2} \cdot r^2 \cdot \cos\phi \cdot d\phi dr}{A_0 \int_0^R \int_0^{\frac{\pi}{2}} e^{-\alpha r^2} \cdot r \cdot d\phi dr}$$

$$= \frac{\int_0^R \int_0^{\frac{\pi}{2}} e^{-\alpha r^2} \cdot r^2 \cdot \cos\phi \cdot d\phi dr}{\int_0^R \int_0^{\frac{\pi}{2}} e^{-\alpha r^2} \cdot r \cdot d\phi dr} \cdot \tan\theta$$

$$= \frac{\int_0^R e^{-\alpha r^2} \cdot r^2 \cdot \int_0^{\frac{\pi}{2}} \cos\phi \cdot d\phi dr}{\int_0^R e^{-\alpha r^2} \cdot r \int_0^{\frac{\pi}{2}} \cdot d\phi dr} \cdot \tan\theta$$

$$= \frac{\int_0^R r^2 e^{-\alpha r^2} \cdot dr}{\frac{\pi}{2} \int_0^R r e^{-\alpha r^2} \cdot dr} \cdot \tan\theta$$

$$= \frac{\sqrt{\pi}\, erf\left(\sqrt{\alpha} R\right) \cdot e^{\alpha R^2} - 2\sqrt{\alpha} R}{\alpha^{\frac{1}{2}} \pi \left(e^{\alpha R^2} - 1\right)} \cdot \tan\theta$$

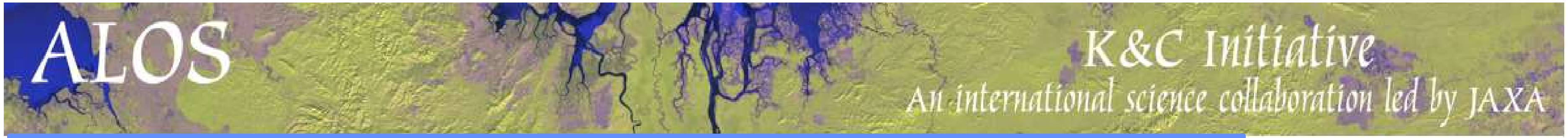


Maclaurin's expansion

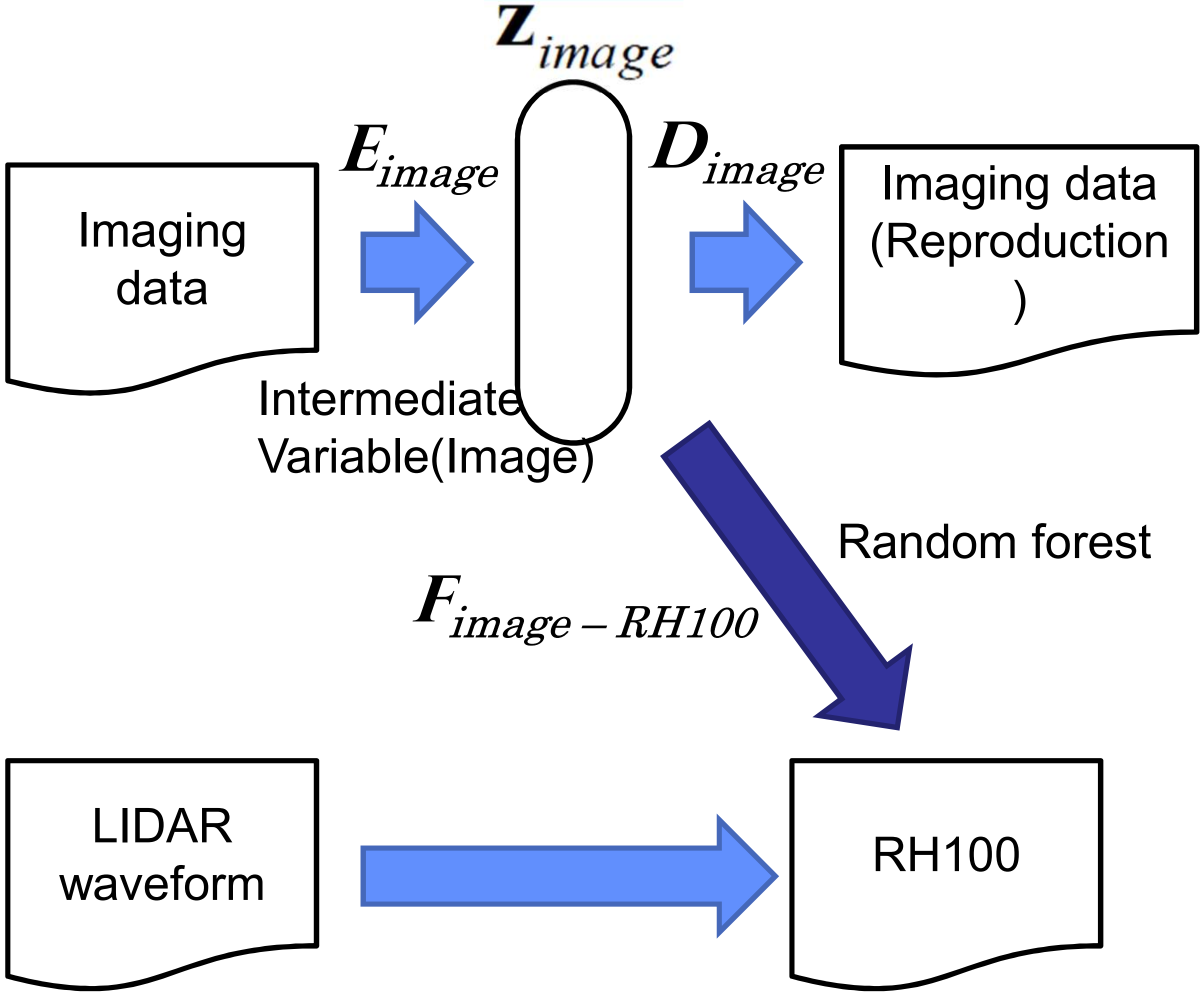
Because the beam intensity is constant

$$\bar{h} \approx \frac{1}{\pi}\left(\frac{4}{3} - \frac{2\alpha R^2}{15} - \frac{\alpha^2 R^4}{315} + \frac{2\alpha^3 R^6}{945} + \frac{\alpha^4 R^8}{13860} + \cdots\right) \cdot R \tan\theta$$

$$\approx 0.382 \cdot \frac{1}{2} \cdot D_f \tan\theta$$



RH100 estimation from imager data using machine learning



Non-linear projection of image to low-dimensional intermediate variable Z_{image} with VAE (Valiational Autoencoder)

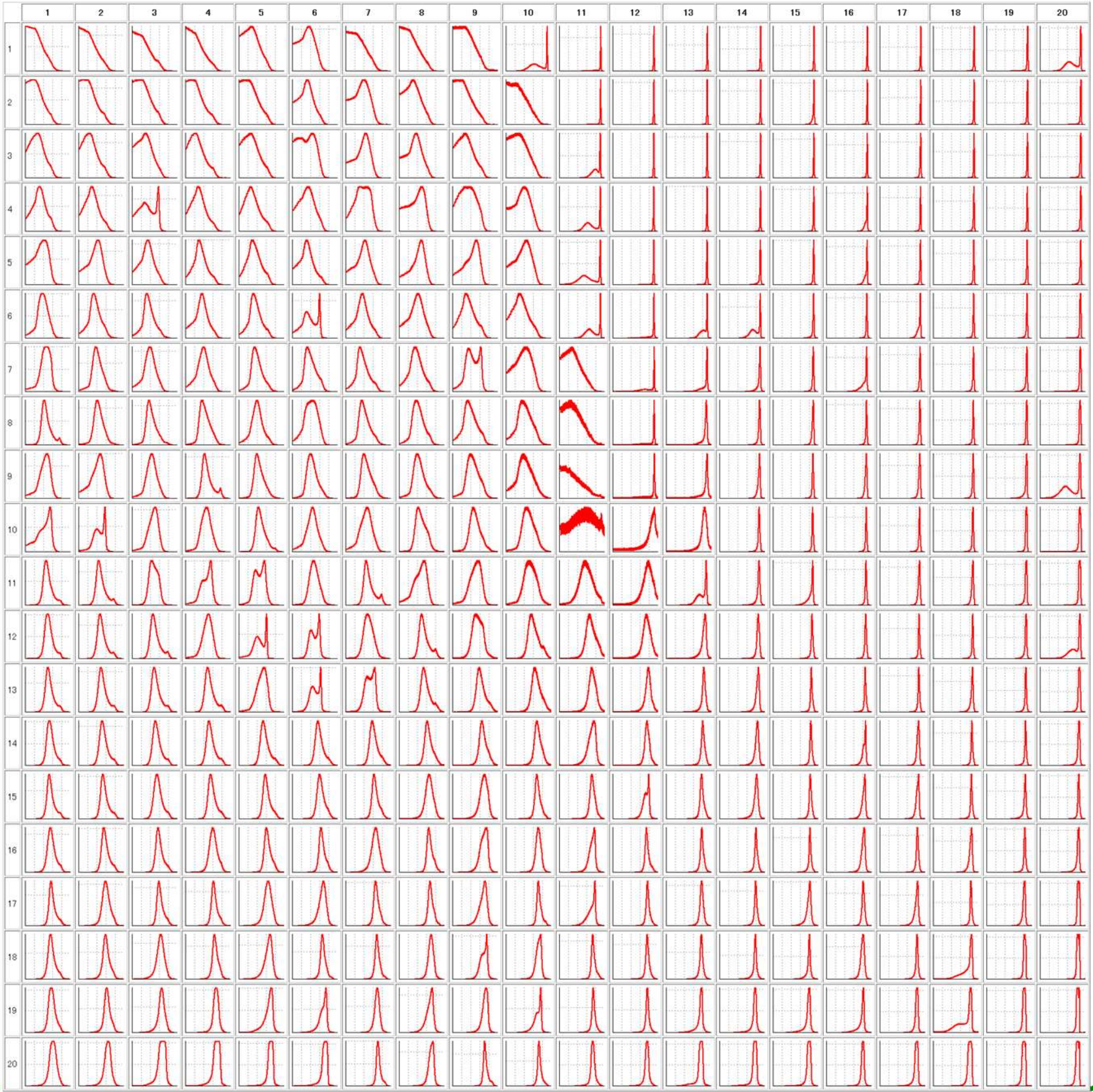
Learning the image relation (E_{image}, D_{image} can be obtained)

Learning the relationship between the image's intermediate variable zimage and RH 100 with RandomForest ($F_{image \rightarrow RH\ 100}$ is obtained)

Combining E_{image}, $F_{image \rightarrow RH\ 100}$ makes it possible to generate RH100 maps from imager images

Waveform classification of ICESat/GLAS data

20 * 20 classification (**Self-organizing maps)**



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	2	2	2	2	2	2	2	2	2	2	9	9	9	9	9	9	9	9	9	2
2	2	2	2	2	2	2	2	2	2	2	9	9	9	9	9	9	9	9	9	9
3	2	2	2	2	2	2	2	2	2	2	2	9	9	9	9	9	9	9	9	9
4	2	2	2	2	2	2	2	2	2	2	2	9	9	9	9	4	9	9	9	9
5	2	2	2	2	2	2	2	2	2	2	2	9	9	9	9	4	9	9	9	9
6	2	2	2	2	2	2	2	2	2	2	2	2	2	2	9	9	8	9	9	9
7	2	2	2	2	2	2	2	2	2	2	2	2	9	9	9	9	9	9	9	2
8	2	2	2	2	2	2	2	2	2	2	2	2	9	9	9	9	9	9	9	9
9	2	2	2	2	2	2	2	2	2	2	2	2	9	9	9	9	9	9	9	2
10	2	2	2	2	2	2	2	2	2	2	2	2	2	9	9	9	9	9	9	2
11	2	2	2	2	2	2	2	2	2	2	2	2	2	9	9	9	9	9	9	2
12	2	2	2	2	2	2	2	2	2	2	2	2	9	9	9	9	9	9	9	2
13	2	2	2	2	2	2	2	2	2	2	2	9	9	9	9	9	9	9	9	9
14	2	2	2	2	2	2	2	2	2	2	9	9	9	9	9	4	9	9	9	9
15	2	2	2	2	2	2	2	2	2	2	9	9	9	9	9	9	9	9	9	9
16	2	2	2	2	2	2	2	2	2	2	9	9	9	9	9	9	9	9	9	9
17	2	2	2	2	2	2	2	2	2	2	2	9	9	9	9	9	9	9	9	11
18	2	2	2	2	2	2	2	2	2	9	2	9	9	9	9	9	9	2	9	11
19	2	2	2	2	2	2	2	2	9	2	9	9	2	9	2	9	9	2	9	11
20	2	2	2	2	2	2	2	2	2	9	2	9	2	2	9	9	9	2	11	11

Land covering by MOD 12

- 2 Broadleaf evergreen forest(Green)
- 4 Broadleaf deciduous forest
- 9 Savanna
- 11 wetland