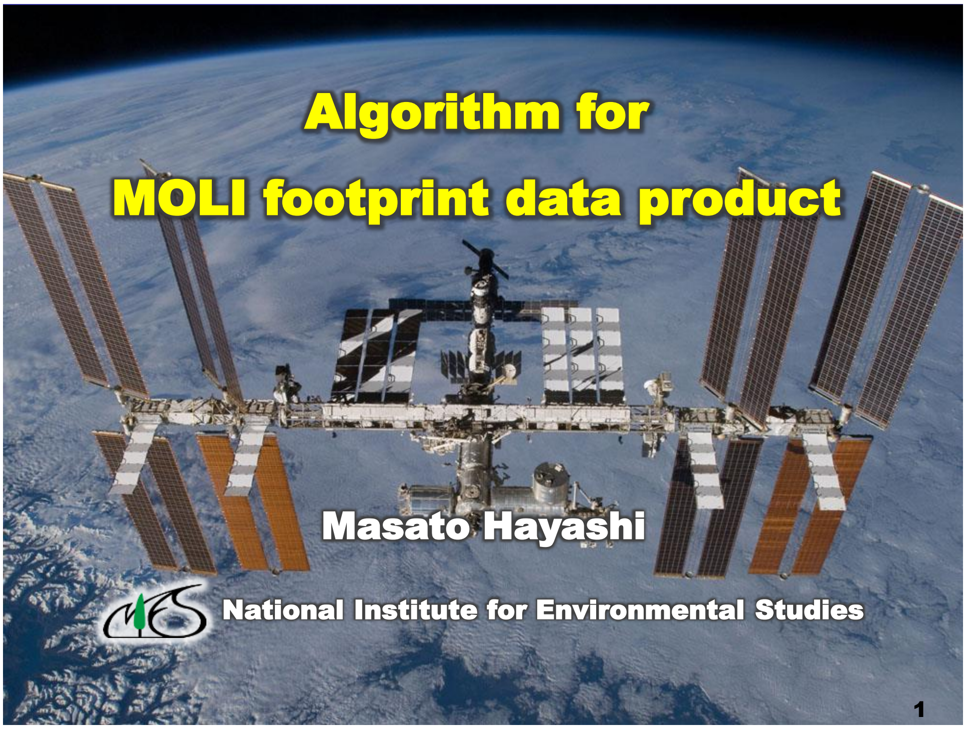
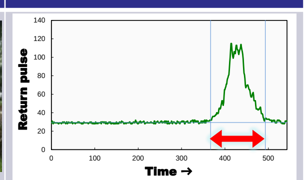
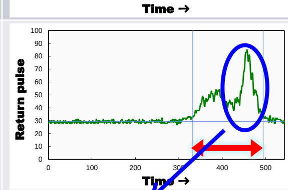
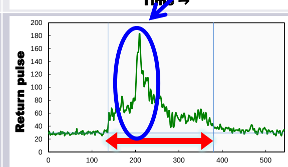


Algorithm for MOLI footprint data product

Masato Hayashi

National Institute for Environmental Studies

1. Waveform of spaceborne LiDAR

Forest type	Height & Biomass	Photo	ICESat/GLAS waveform
Oil palm plantation	H = 5 m AGB = 44 t/ha		
Sakhalin fir plantation	H = 18 m AGB = 132 t/ha		
Forest reserve	H = 28 m AGB = 295 t/ha		

2. Canopy height & forest biomass

Canopy height and forest biomass are the most fundamental parameters representing forest resources.

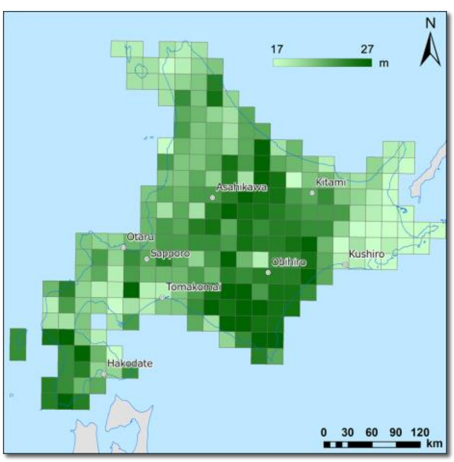
They can be easily converted to carbon stock using carbon fraction or allometric equation.

Monitoring and mapping are essential for carbon cycle study and REDD+ implementation.

Canopy height and forest biomass are fundamental MOLI-products.

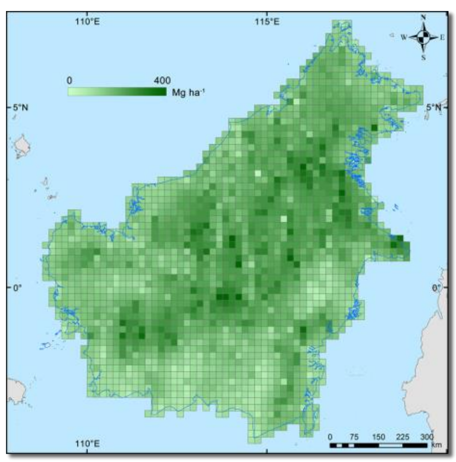
3. Observation of ICESat/GLAS

Hokkaido



Canopy height map

Borneo

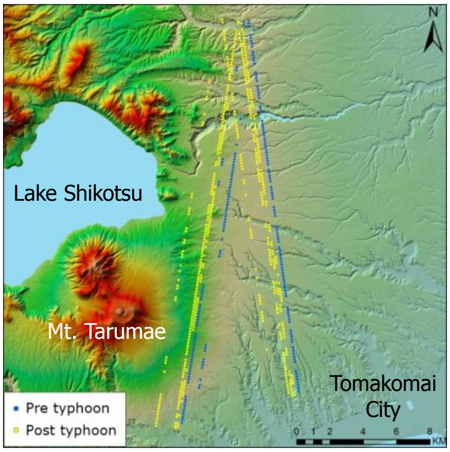


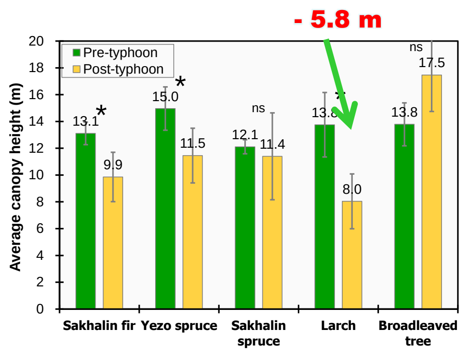
Aboveground biomss map

[Hayashi et al., *Carbon management*, 2015]

3. Observation of ICESat/GLAS

Forest disturbance observation (typhoon Songda)





[Hayashi et al., *Remote sensing of environment*, 2015]

4. MOLI footprint data product

- **<u>MOLI level-2 product</u>**
  - Footprint data product
    - Waveform clustering
    - Ground elevation
    - Canopy height
    - Aboveground biomass
  - Along-track 1 km-width product
    - Canopy height
    - Aboveground biomass

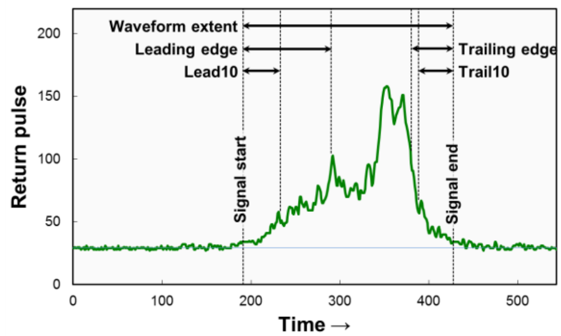
- **<u>Specification of canopy height estimation</u>**
  - Object : SNR > 10, ground slope < 30°
  - Accuracy : RMSE < 3 m

- **<u>Specification of aboveground biomass estimation</u>**
  - Object : SNR > 10, ground slope < 30°
  - Accuracy : RMSE < 20 t/ha

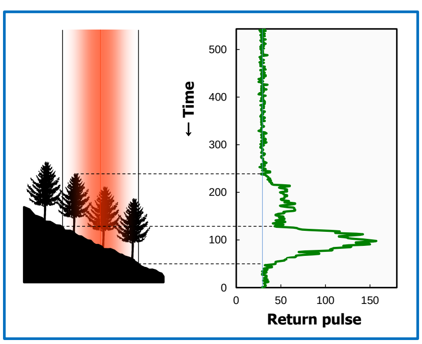
5. Canopy height estimation

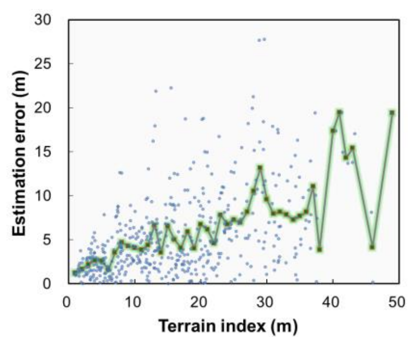
Methodology in previous studies

- Direct method
  - RH100
  - *tan-θ* correction
- Empirical method
  - DEM data
  - Edge extent



5. Canopy height estimation





Pulse broadening according to ground slope affects the estimation accuracy greatly.

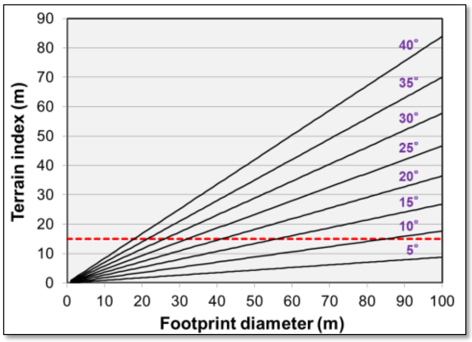
MOLI takes measures against this effect.

[Hayashi et al., *ISPRS Journal of Photogrammetry and Remote Sensing*, 2013]

6. MOLI’s measures against slope

Measure 1 : Optimization of footprint size

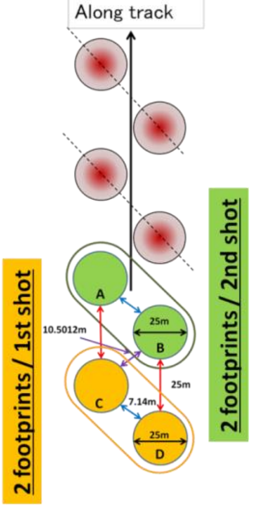
Small	← Footprint size →	Large
High	← Estimation accuracy →	Low
Insensitive	← Ground detection →	Sensitive



MOLI’s footprint size = 25 m

6. MOLI’s measures against slope

Measure 2 : Measurement of ground slope



Footprints are located adjacently.

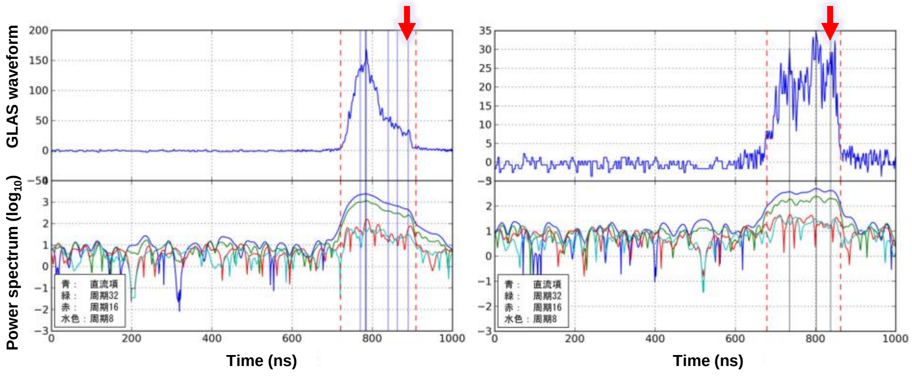
Ground slope can be calculated.

It can be used to correct canopy height estimates.

7. MOLI's algorism for canopy height

Direct method

- ❖ Height difference between signal start and ground peak ⇒ canopy height.
- ❖ Ground peak detection: Gaussian-fitting or short-time Fourier transform (STFT).
- ❖ STFT is a robust method even for noisy waveform.



[Y. Sawada, *private communication*]

7. MOLI's algorism for canopy height

Empirical method

- ❖ We will develop empirical models using waveform extent and some parameters.
- ❖ The models have an ability to correct pulse broadening in sloped area.
- ❖ We will develop the models based on field data, after MOLI launch.

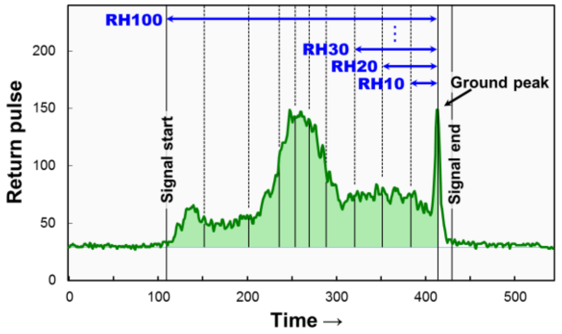
Area	Estimation model	Reference
China	$H = 0.707\ WE - 0.506\ TI$	Xing *et al.*, 2008
England	$H = 0.96\ WE - 0.53\ TI$	Rosette *et al.*, 2010
United States: Mendocino	$H = 0.87\ WE - 0.29\ TI$	Chen, 2010
Santa Clara	$H = 0.64\ WE - 0.27\ TI$	
Lewis	$H = 0.84\ WE - 0.31\ TI$	
Japan	$H = 0.899\ WE - 0.431\ TI$	Hayashi *et al.*, 2013
⋮	⋮	⋮

WE: Waveform extent, *TI*: Terrain index

8. Aboveground biomass estimation

Methodology in previous studies

- Using canopy height
- Using waveform parameters
  - Multiple regression
  - Machine learning



9. MOLI's algorism for aboveground biomass

Method of using waveform parameters

- We will develop empirical models using waveform parameters.
- The models will be expected to provide accurate estimates.
- We will develop the models based on field data, after MOLI launch.

Example of waveform parameter

Parameter	Description
WE	**Waveform extent**
RH10, RH20, … , RH100	**Relative height**
LE, TE	**Edge extents**
θ	**Front slope angle**
Skew, Var	**Skewness and variance of waveform**
⋮	⋮

10. Future plans

1. **Sample waveform data collection using airborne LiDAR.**
2. **Algorithm development using the sample waveform data.**
3. **Ground-truth data collection by field measurements or airborne LiDAR observations.**