An underlying topography determination approach over Forested area based on Interferometric Phase Histogram using Spaceborne Tandem-X InSAR and GEDI LiDAR Data

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Outline

- Brief Introduction and motivations
- Methodology
- Experiments and studies
- Conclusion

□ Major remote sensing methods for featuring forest :

- **Multi-/hyper spectral、Multi-angle optical remote sensing based methods:**

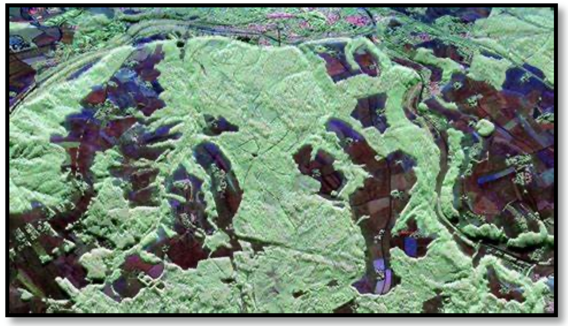
  ☺ Higher spatial resolution, and better morphological interpretation;
  ☹ Prone to weather condition;

- **Light Detection and Ranging (LiDAR) based methods:**

  ☺ Highest vertical measurement accuracy;
  ☹ Prone to cloudy weather condition;

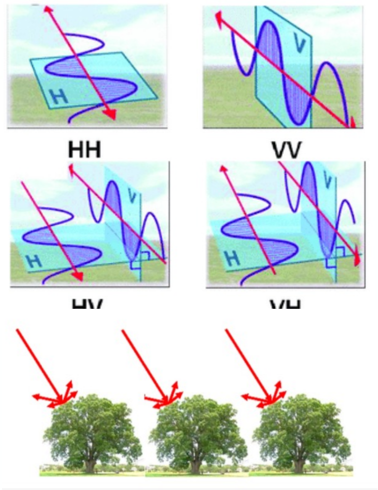
- **Synthetic Aperture Radar (SAR) based methods:**

  ☺ A well balance between wall-to-wall mapping and vertical measurements accuracy;
  ☺ Great penetration capabilities at lower frequency;

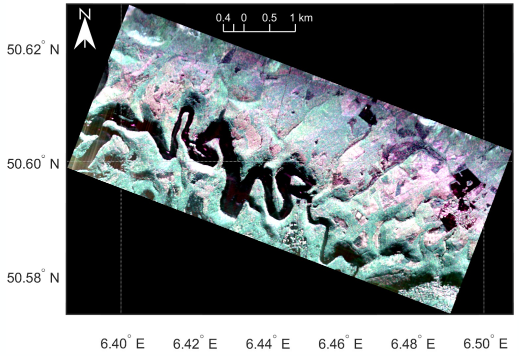


SAR based methods

PolSAR backscatter

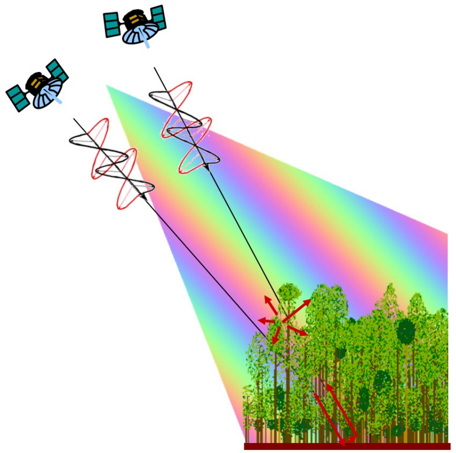


$\text{R:}|HH+VV|$, $\text{G:}|2HV|$, $\text{B:}|HH-VV|$

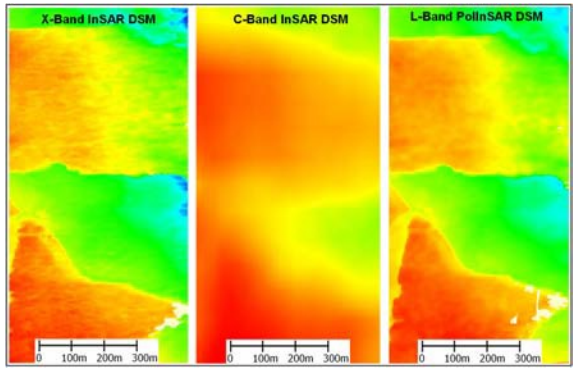


Distinguish multiple scattering mechanisms

InSAR

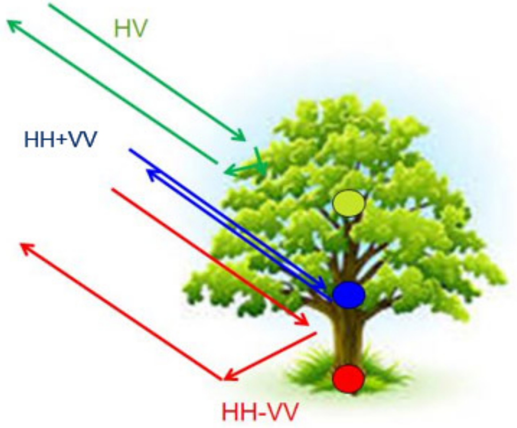


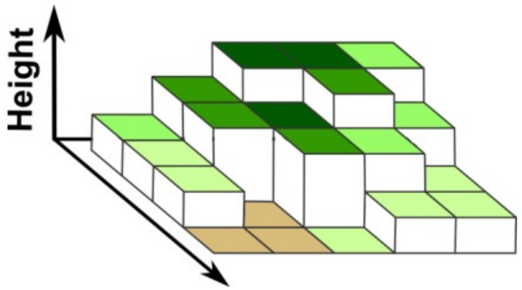
(A. Moreira, et al., 2015)



Estimate PS height or DS equivalent height

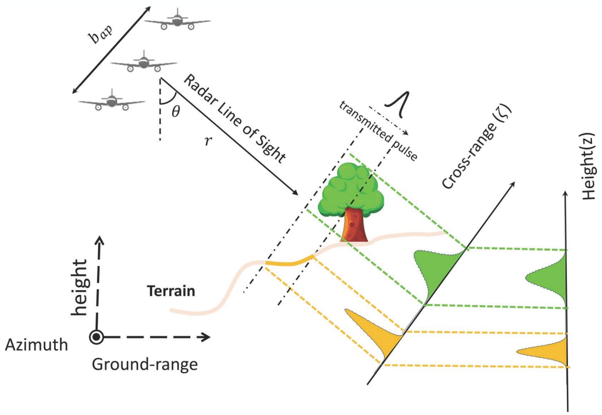
PolInSAR



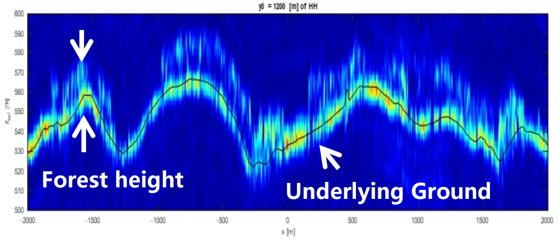


Height inversion for different scattering mechanisms

TomoSAR



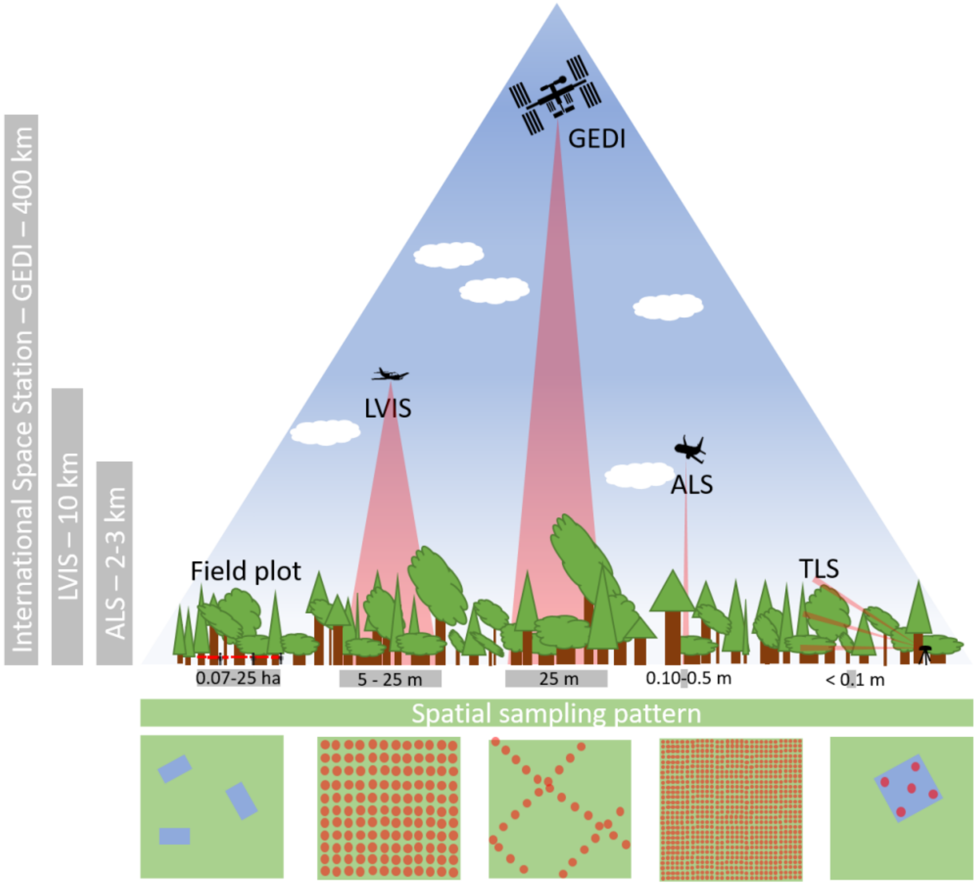
P-band tomogram



Forest 3D direct mapping

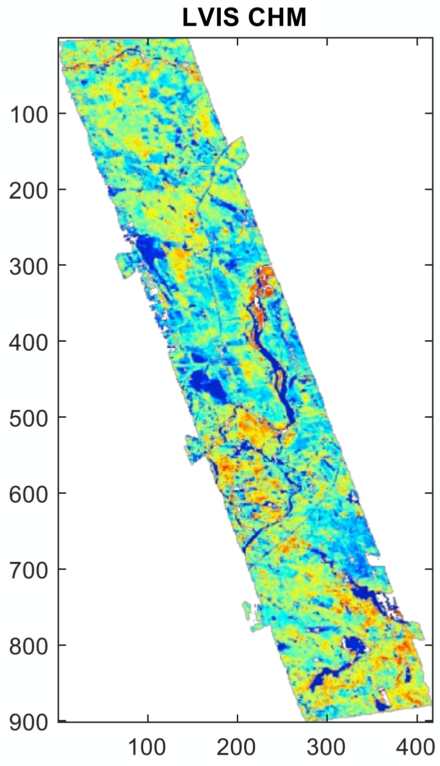
LiDAR based inversion

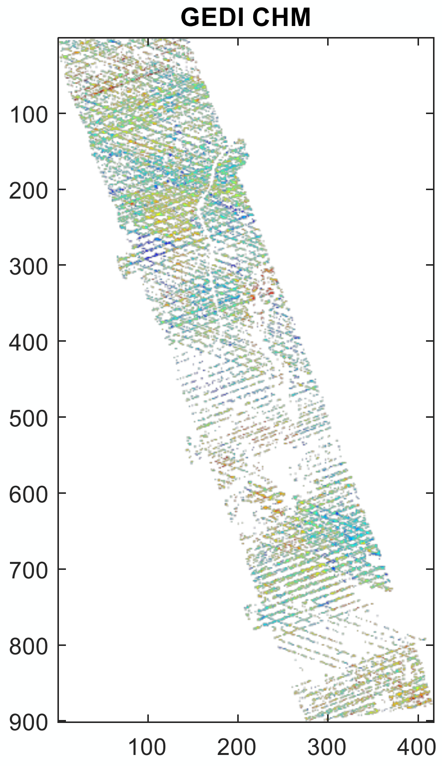
- **Sensitivity to vertical forest structure by using dense pulses penetrating the holes between leaf**



Credit: University of Maryland

Airborne vs Spaceborne





Spaceborne footprint ~25m

Cover the Research site of this study

A review

- A short review of forest investigation based on spaceborne observations

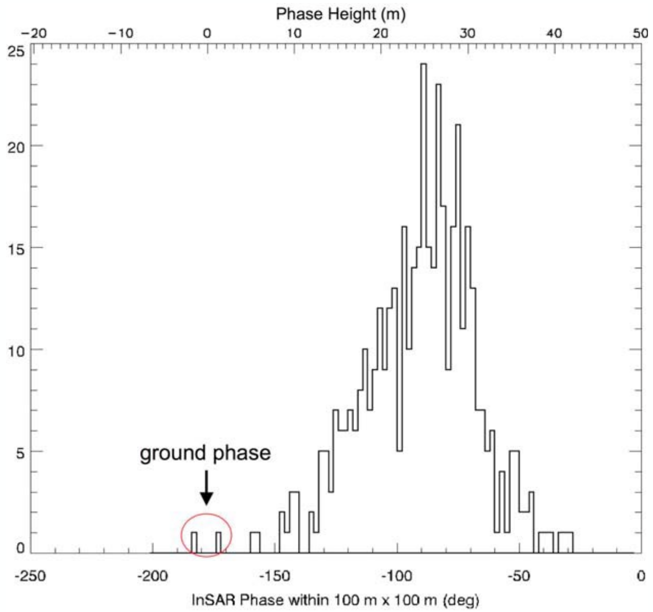
	Spaceborne LiDAR	Pol-SAR backscatter	PolInSAR	Repeat-pass InSAR	Single-pass InSAR
polarization	—	co-/cross pol	Full-pol	Mono- / dual-/ full-pol	Co-pol
Frequency	—	L- / P- band	X- / L-band	C- to L-band	X- band
Number of satellites	Single	Mono-static	Bistatic	Monostatic	Bistatic
weakness	Sparse Sampling	Saturation problem	Limited availability	Temporal Decorrelation	Limited penetration
accuracy	Meter level for a 25m footprint	Relatively coarse	meters / hectare	meters / 3-6 hectares	meters / hectares

✓ **TomoSAR based**

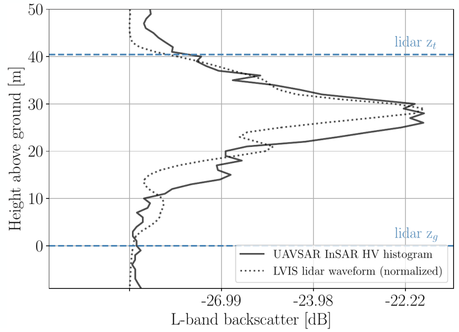
- ESA BIOMASS is forthcoming..

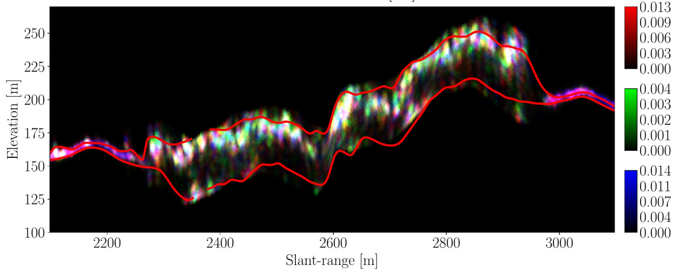
Methodology

- **High-frequency and high-resolution few-look InSAR phase histogram**
  - ✓ **possible to penetrate the gaps in the midst of clustered “hard” targets (typically in dense tropical forest).**
  - ✓ **Obtaining LiDAR-like vertical profiles by a statistic of few-look InSAR phase-center height over a local horizontal window**



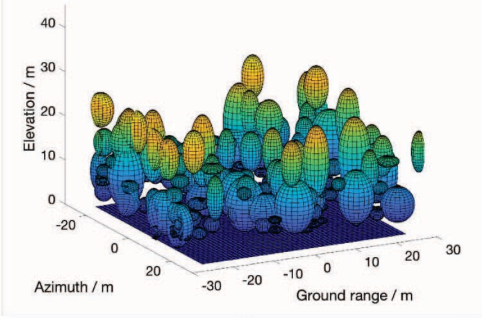
(R. Treuhaft et al, JGR 2008)
Ground finding by Manual Interpretation



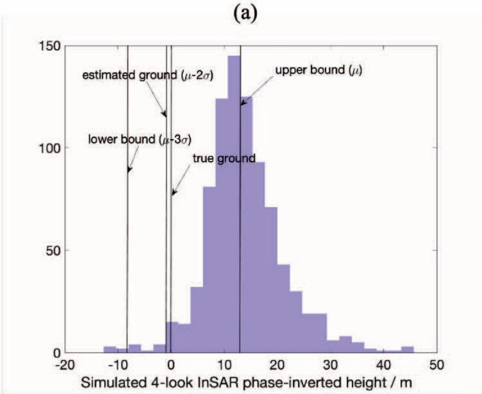


(G. Shiroma et al, TGRS 2020, C. Wu et al,. IGARSS 2023)
Statistic of InSAR-derived height over a local horizontal window

EM simulation



(a)



(b)

(Y. Lei et al, RSE 2021)
Automated ground finding

A statistical function for ground finding

◻ High-resolution InSAR Phase histogram and ground finding

➢ **Histogram formation:**

$$P_H(z_n) = \sum_{m=1}^{M} \text{rect}(\varphi_m, z_n) \quad \text{rect}(\varphi_m, z_n) = \begin{cases} 1 & if \ -\frac{\Delta h}{2} \le \frac{\varphi_m}{k_z} - z_n \le \frac{\Delta h}{2} \\ 0 & otherwise \end{cases}$$

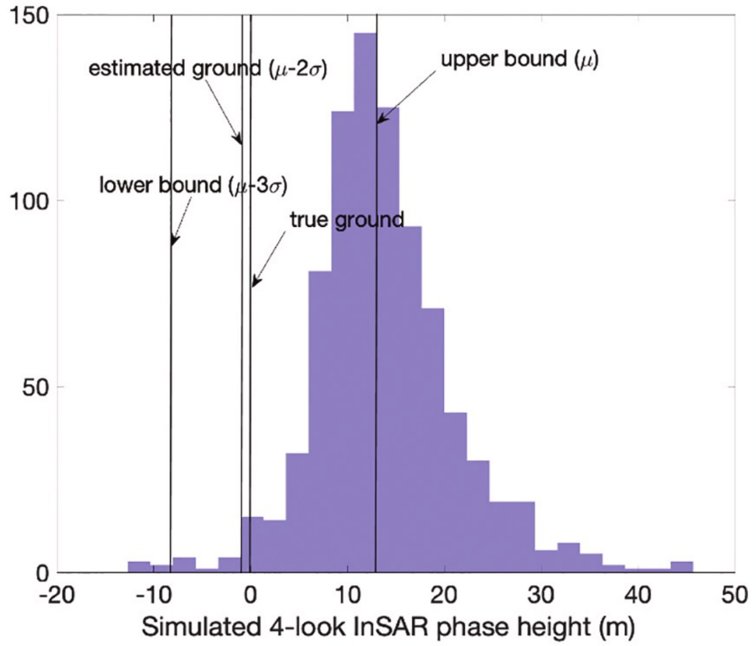
M: is the size of sliding window;
φ_m: single look, or few looks (e.g.,2-4) InSAR phase;
z_n: the height bin;
k_z: the interferometric wavenumber;

➢ **Ground finding in the histogram:**

$$h_g = \alpha(h_v, \lambda, \vartheta, \rho_x, \rho_r, \ldots) \cdot \mu + \beta(h_v, \lambda, \vartheta, \rho_x, \rho_r \ldots) \cdot \sigma$$

h_g: the relative height of underlying ground
μ, σ: first two statistical moments of histogram $P_H(z_n)$
α,β: two linear coefficients depending on factors as follow

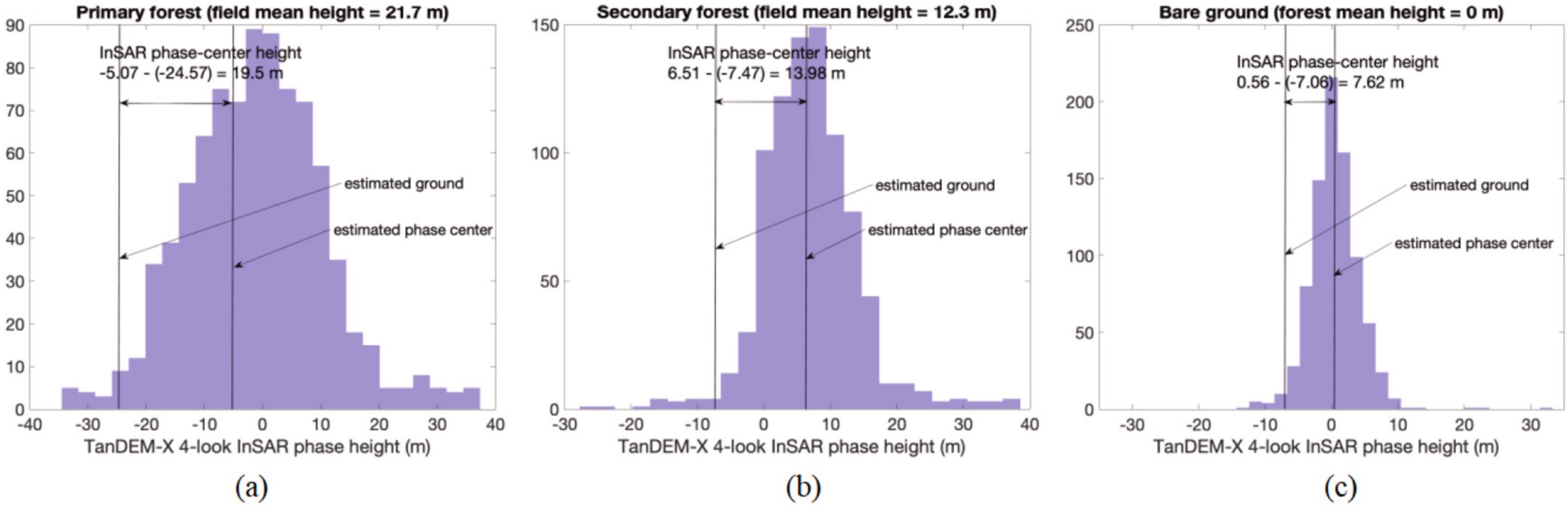
h_v: canopy height as a rough indicator of tree types
λ: wavelength
ρ_x, ρ_r: azimuth / range resolution
ϑ: slopes
……



(Y. Lei et al, RSE 2021)

Examples for different forest types

Over Brazil Amazon area



Histogram illustration of TanDEM-X InSAR phase-center height versus field-measured mean height over two representative field plots of an amazon area (Y. Lei., et al., 2021)

Model determination

☐ The determination of above coefficients

➢ **Constant factor assumption:**

Only field data available at that time, a first simplification was made:

$$h_g = \mu + \beta \cdot \sigma$$

α, β is assumed as a constant value over the scene, $\alpha = 1, \beta = 2$ is assumed and validated over a small area amazon area in 2021.

➢ **Height-dependent factor assumption:**

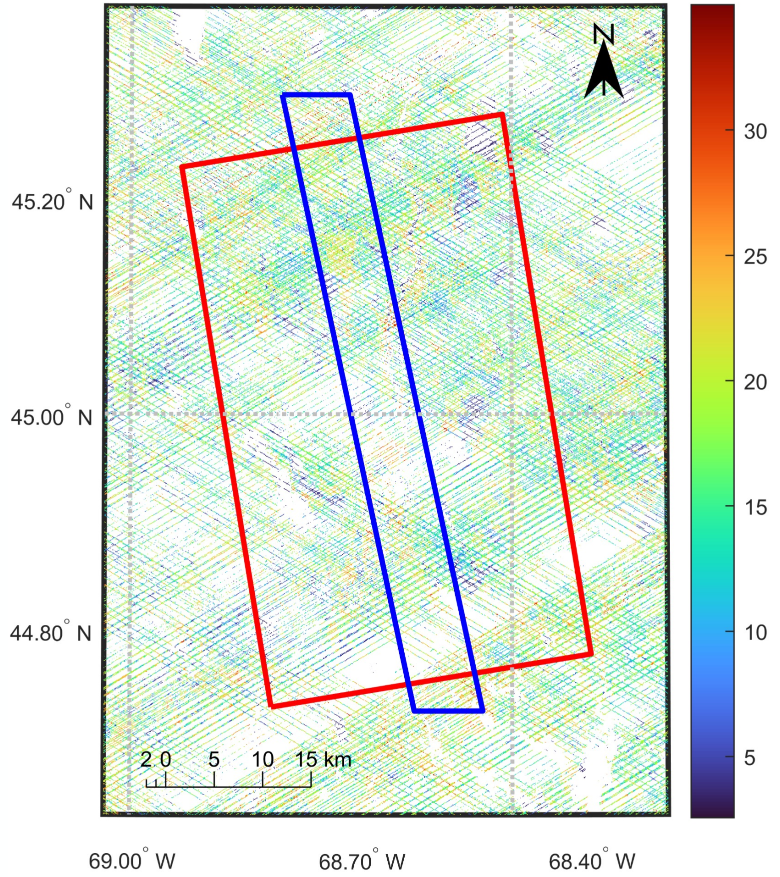
With the rich availability of GEDI samples, we are able to make a step further and recast the β as a function of canopy height:

$$h_g = \mu + \beta(h_v) \cdot \sigma$$

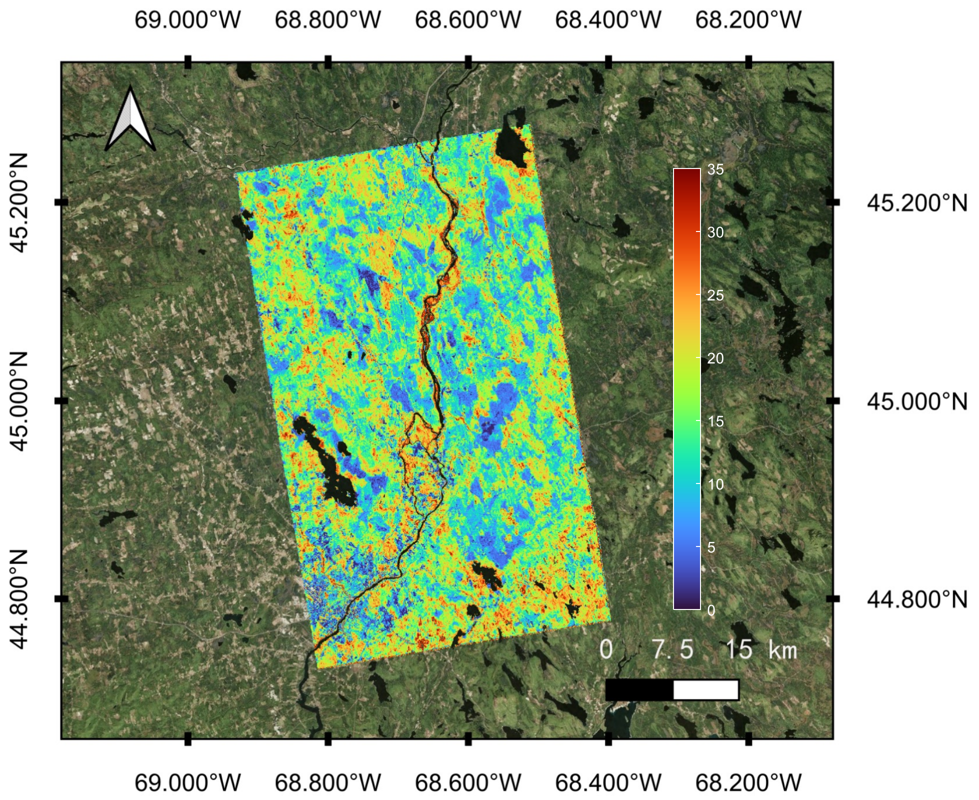
Research site

➢ **Howland Research Forest in the U.S states of Maine**

GEDI Samples of canopy height



RVoG Inverted Forest Height



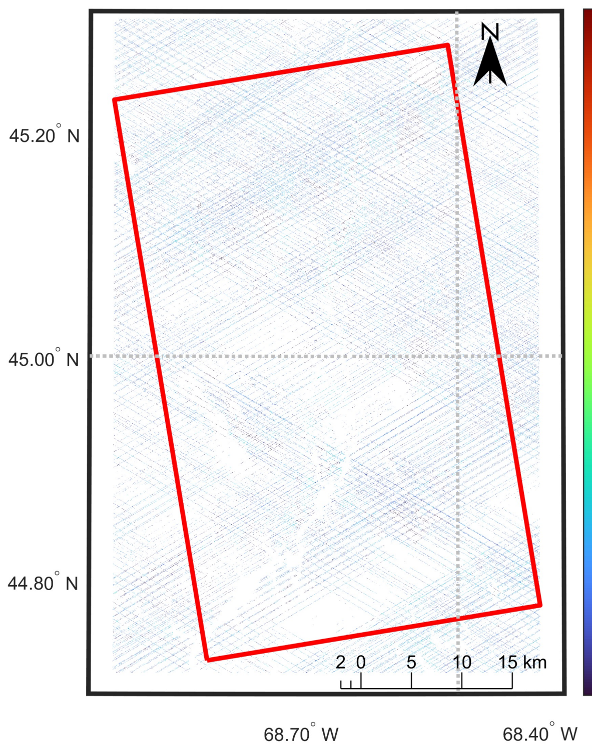
Red box: TDX scene

Blue box: LVIS airborne LiDAR

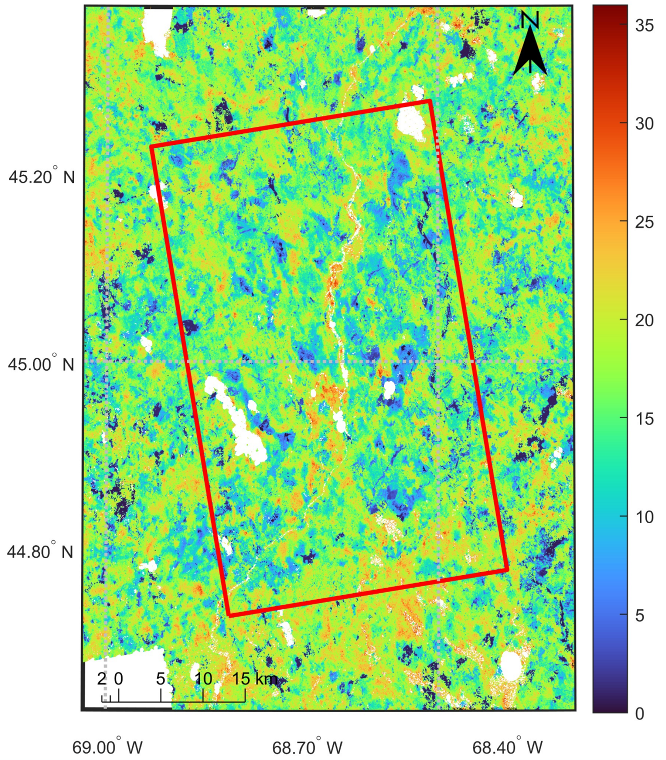
Height dependent factors

➢ **Height-dependent factors retrieval based on GEDI samples**

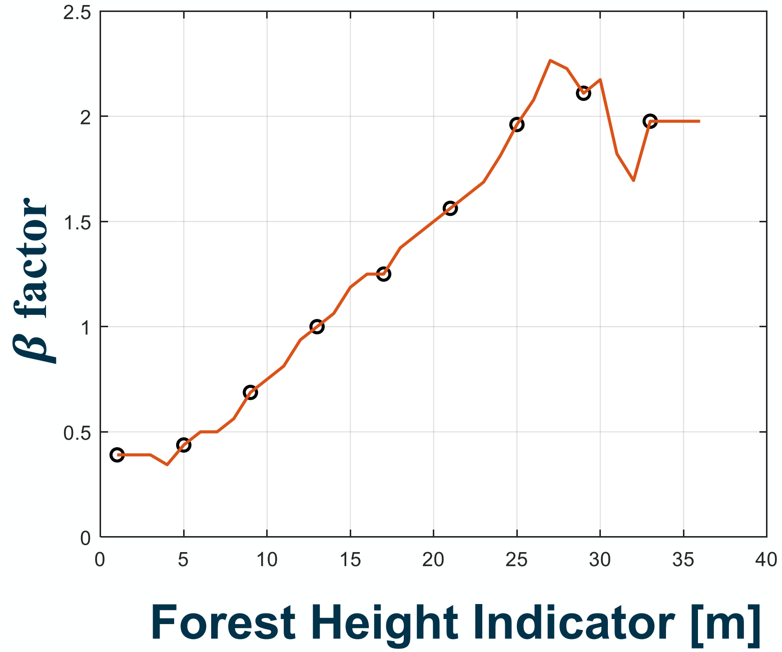
GEDI Samples of underlying ground



Forest height indictors

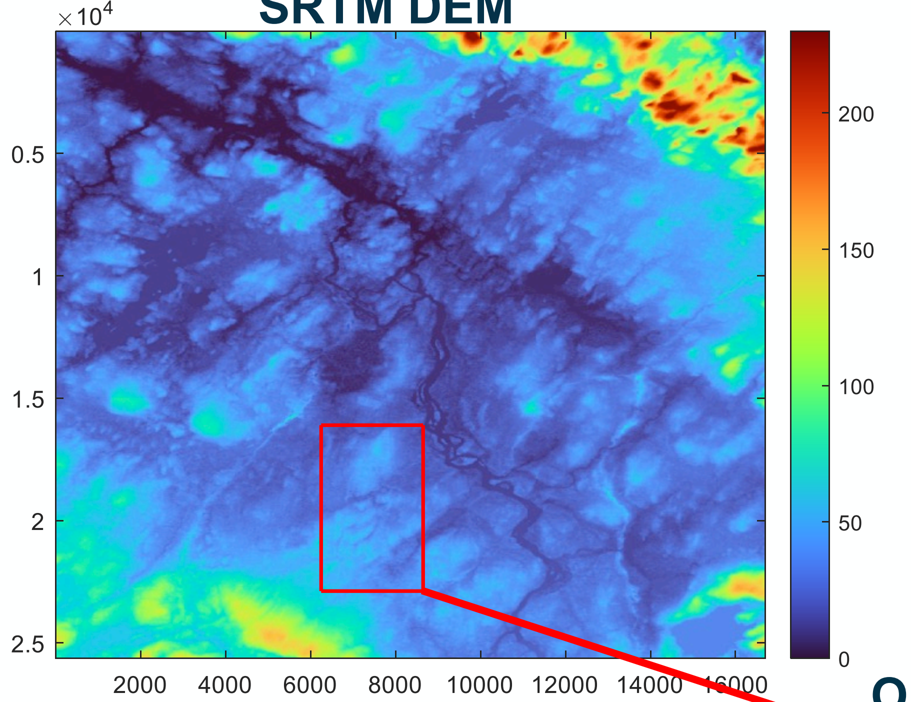


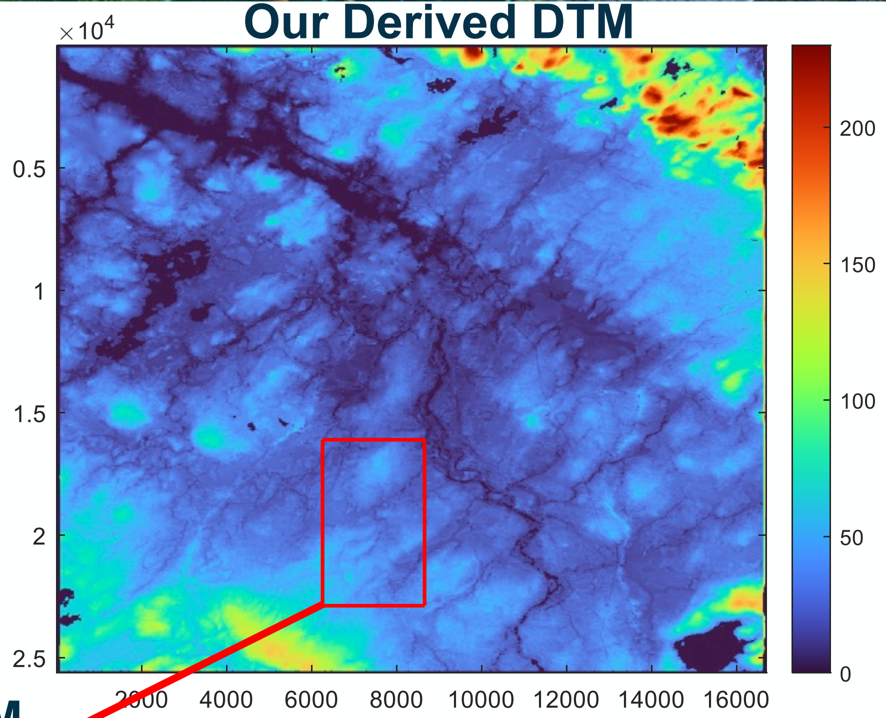
Height-dependent Factors

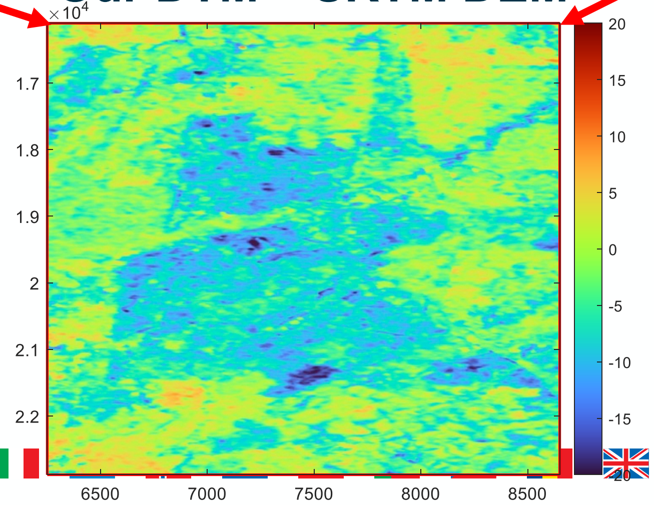


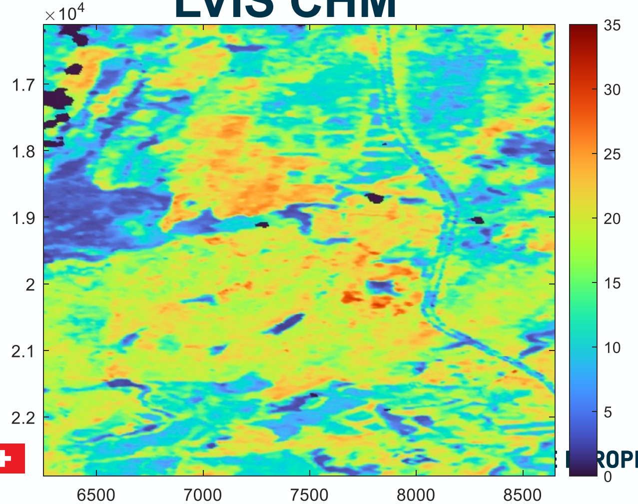
Making joint use of ALOS InSAR and GEDI LiDAR
RMSE: ~3.8m at sub-hectare statistical size
(Y. L., et al., TGRS, 2017,Y. Yu, et al., IGARSS, 2023)

Our derived result





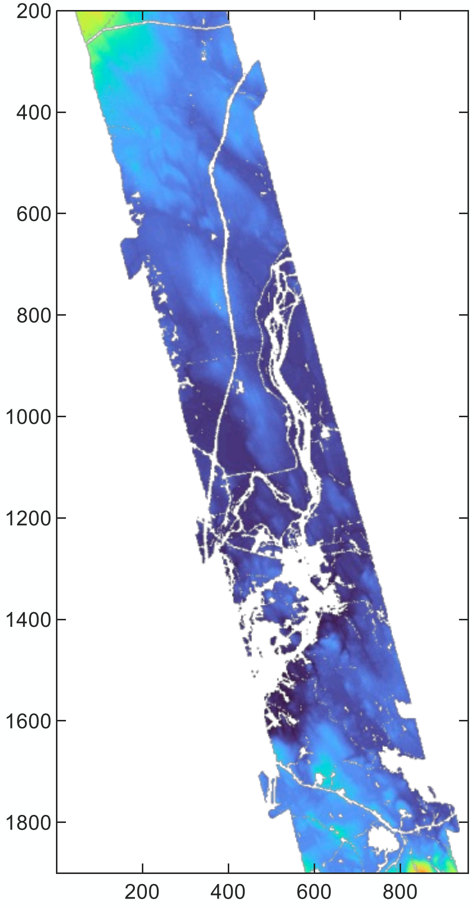




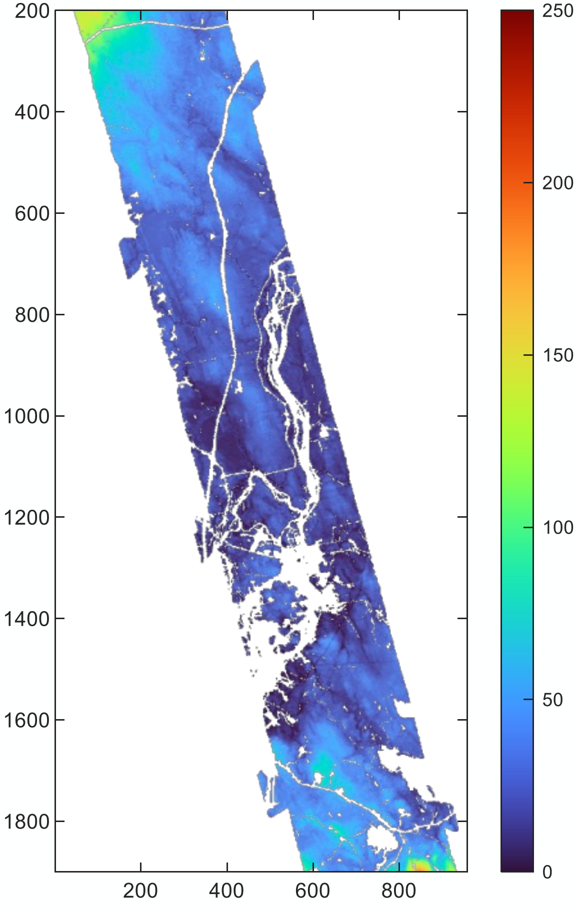
The underlying ground was over-estimated due to the presence of tall trees.

Accuracy assessment for Derived DTM

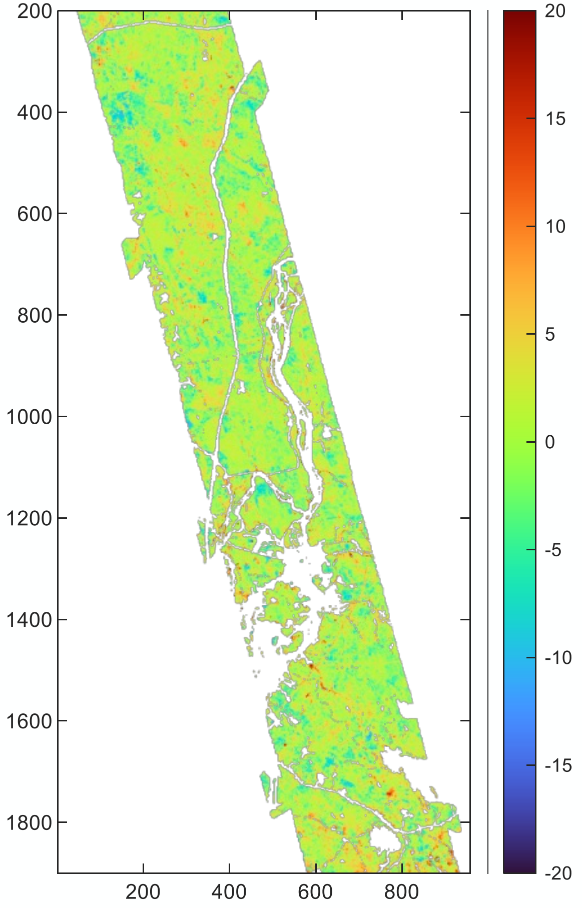
LVIS LiDAR DTM



Our Derived DTM

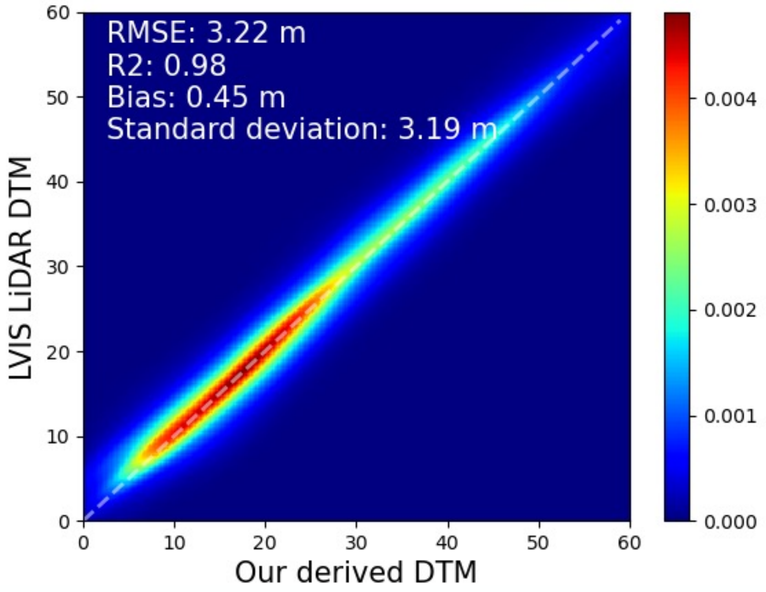


LVIS DTM - Our Derived DTM



Accuracy Assessment

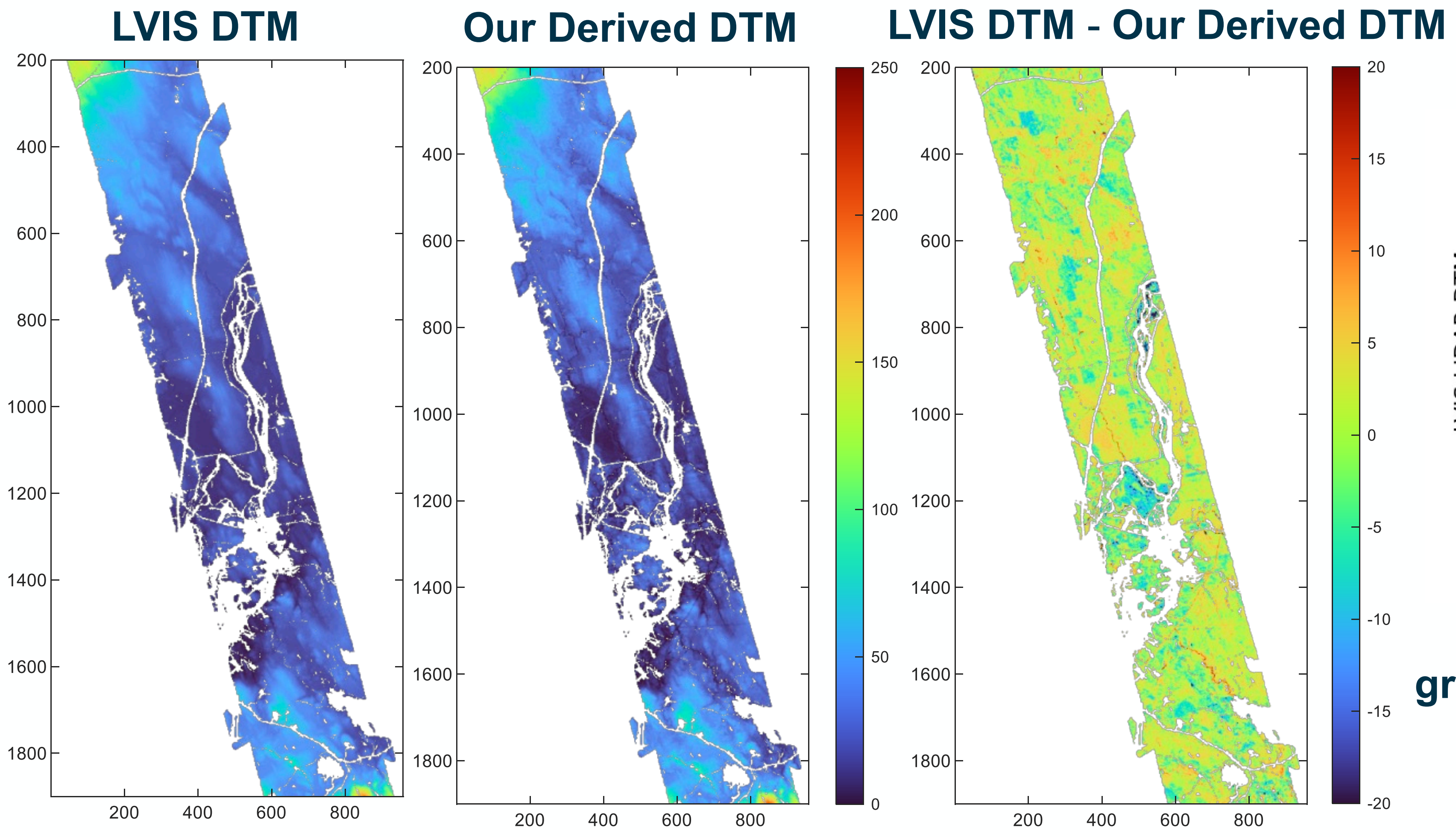
Statistical pixel size ~0.09ha



@30m spatial resolution

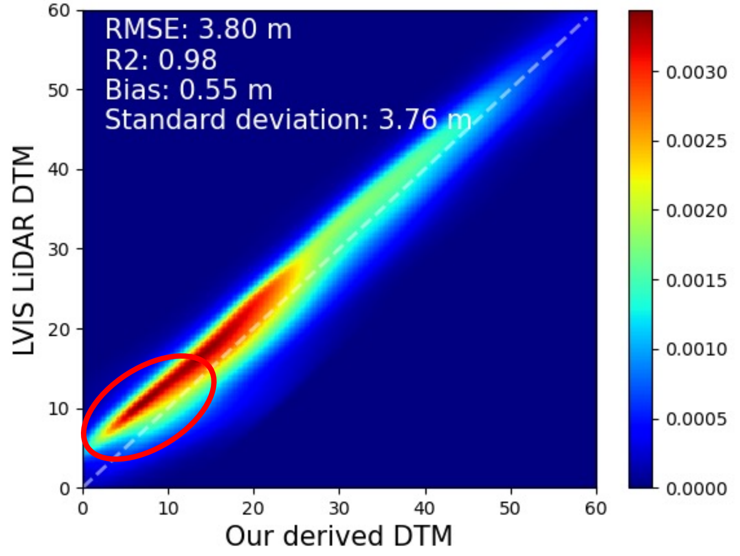
Comparison

☐ Comparison w.r.t the method using a constant factor assumption



@30m spatial resolution

Statistical pixel size ~30m

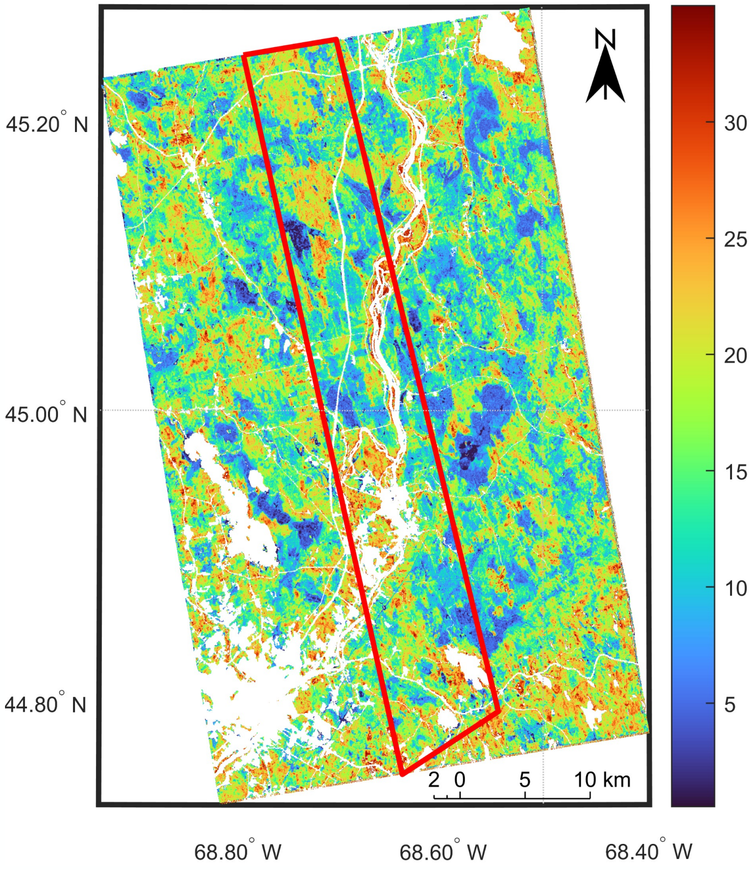


Underestimate the underlying ground for short trees/ bare ground

Canopy height estimation by RVoG

☐ Model based Inversion (RVoG) based on our derived DTM

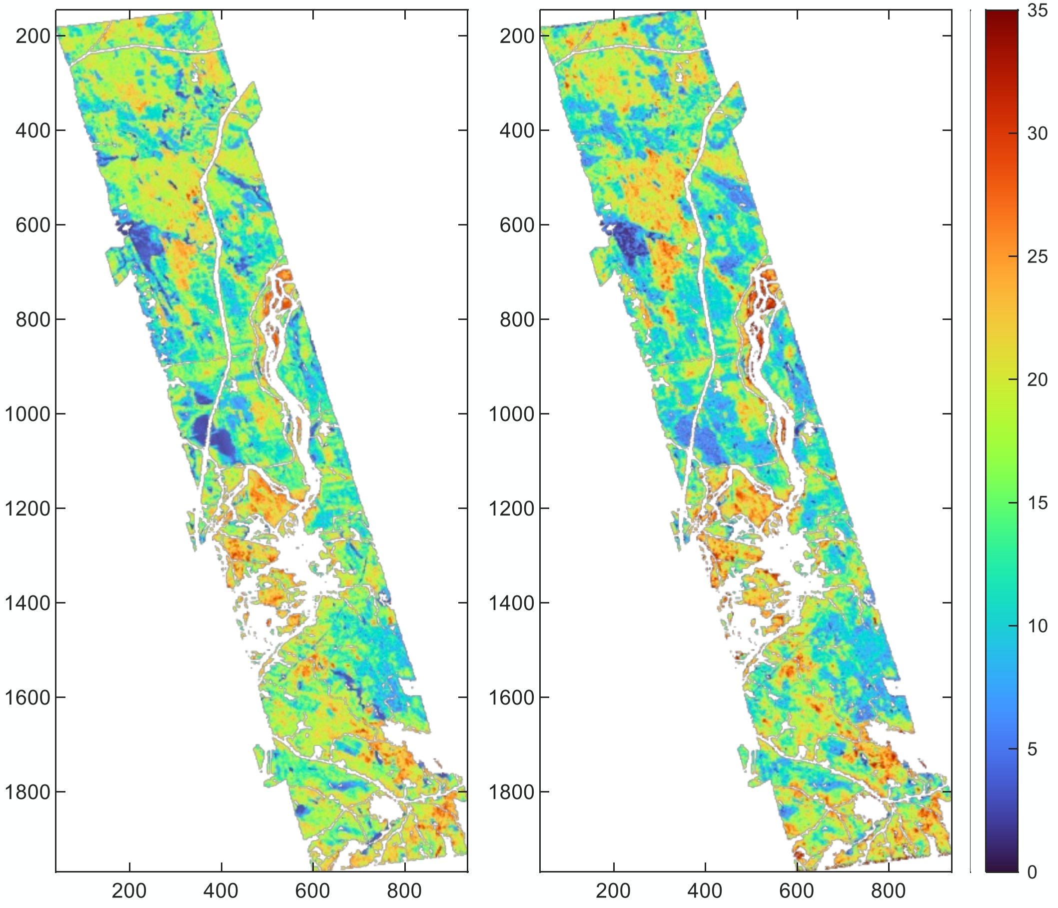
RVoG inversion



Red box: validation site

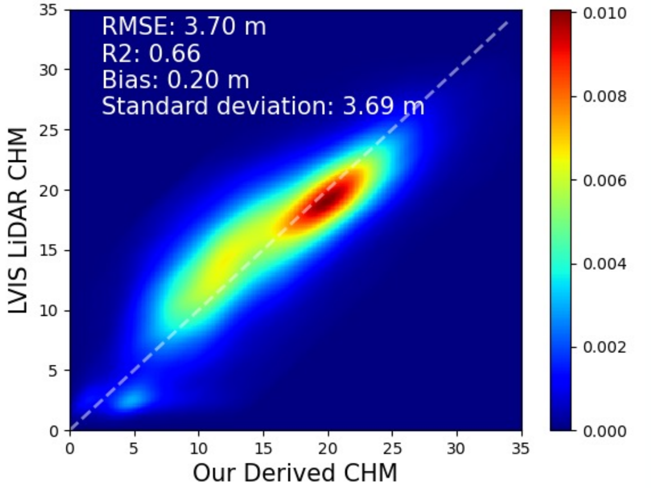
LVIS Airborne CHM

Our Inversion

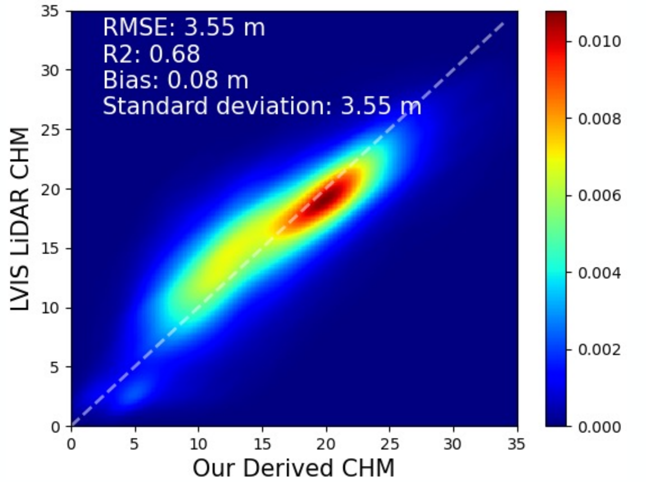


@30m spatial resolution

Statistical pixel size ~0.09ha

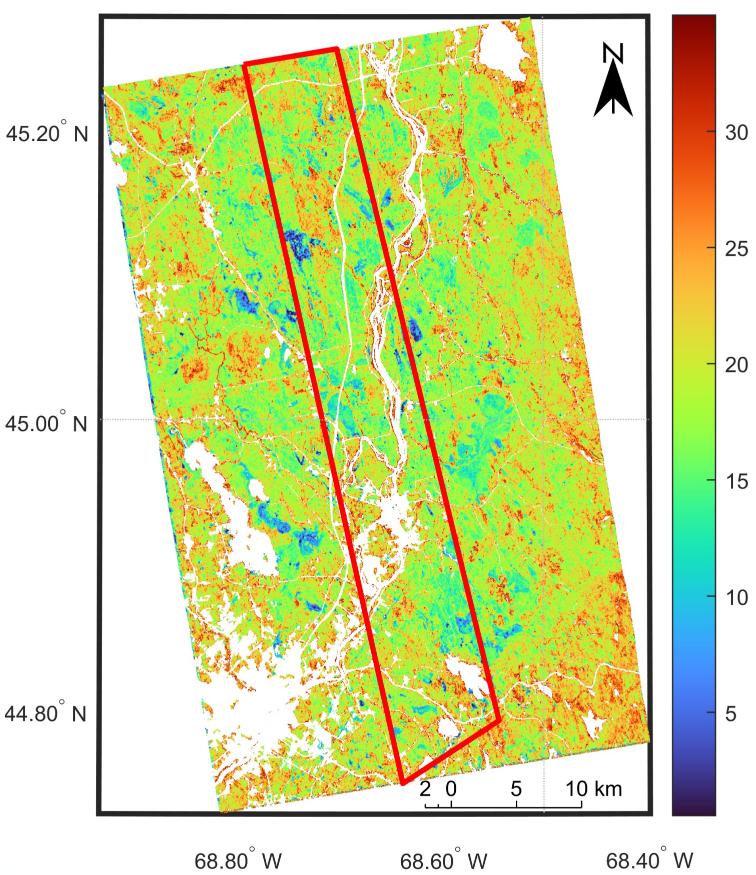


Statistical pixel size ~0.81ha

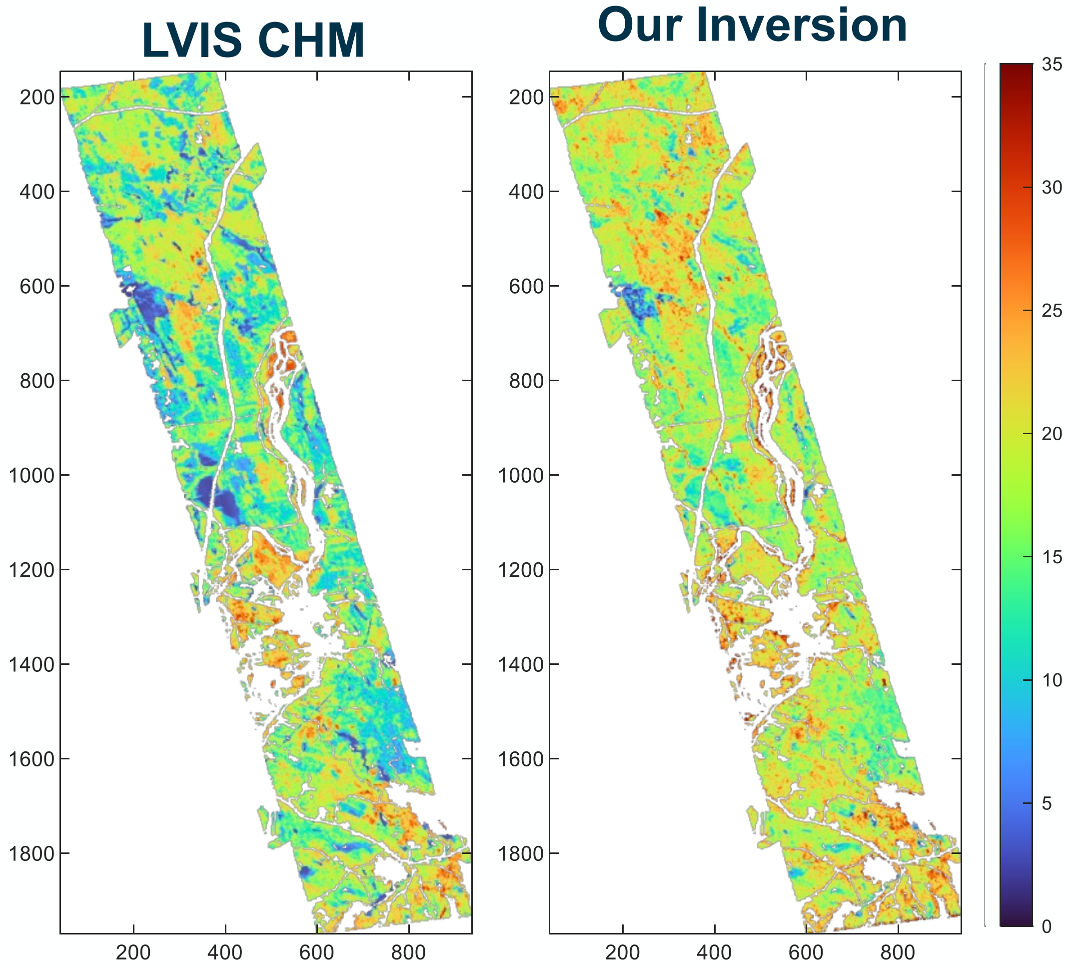


Canopy height estimation by RVoG

- Model based Inversion (RVoG) based on a derived DTM produced using a constant factor assumption

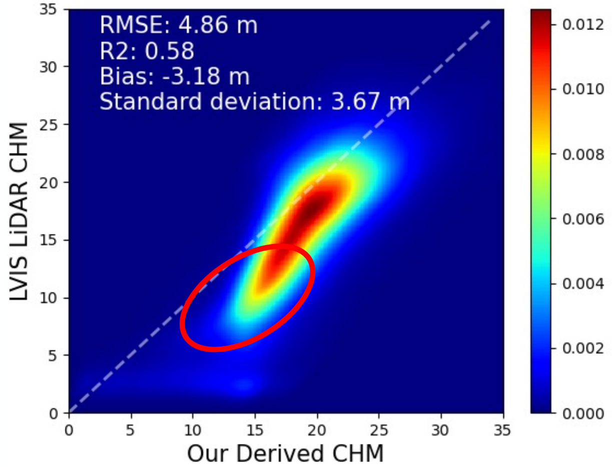


Overall overestimation

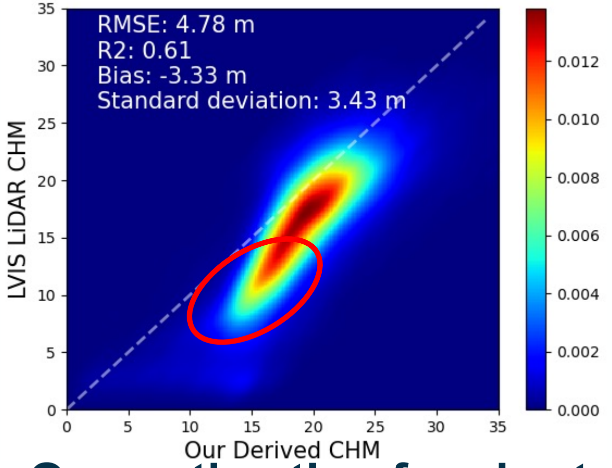


@30m spatial resolution

Statistical pixel size ~0.09ha



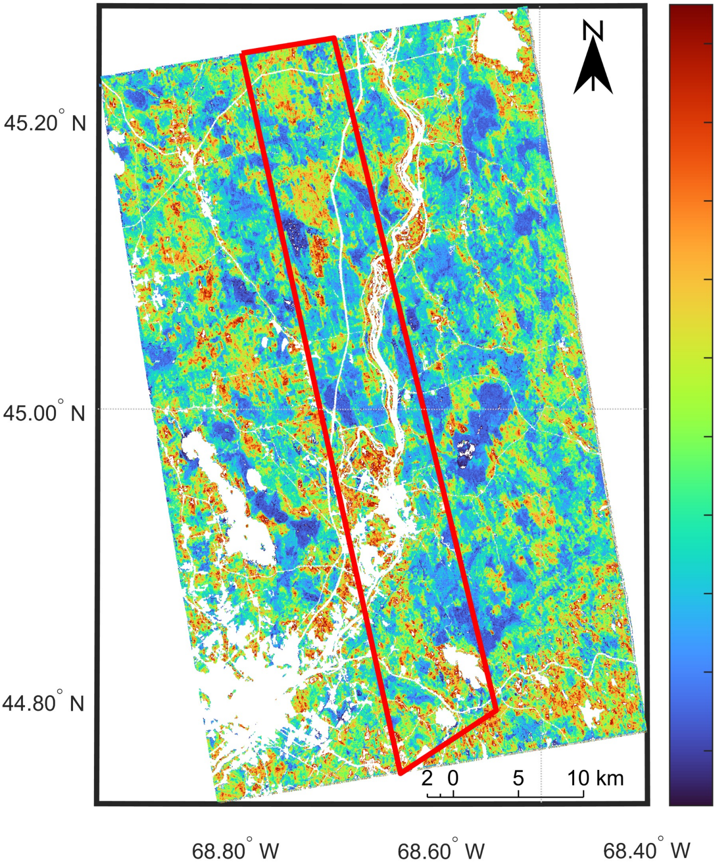
Statistical pixel size ~0.81ha



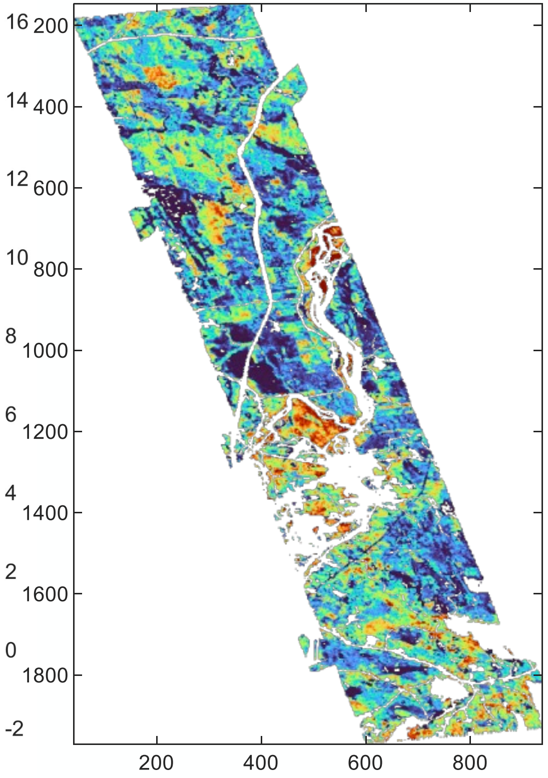
Overestimation for short trees / bare ground

Phase center height VS LiDAR mean height

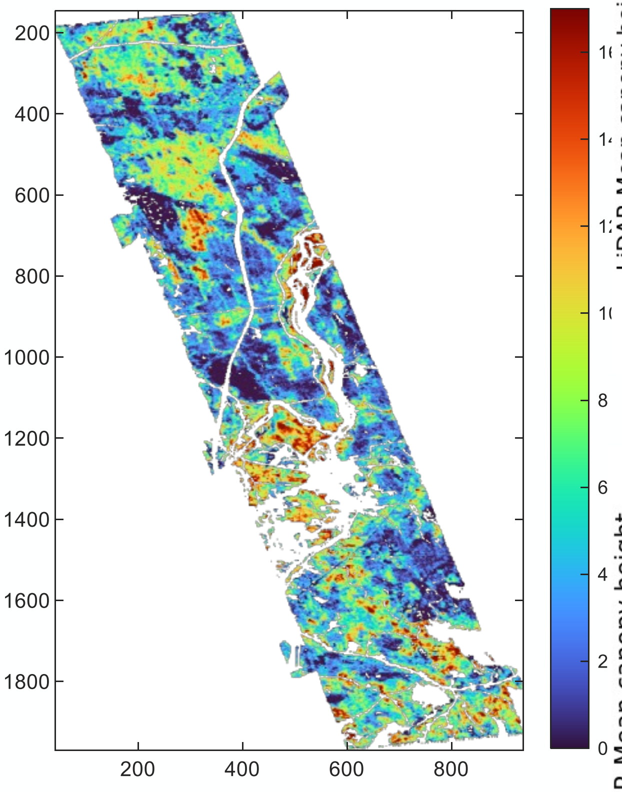
InSAR phase center height



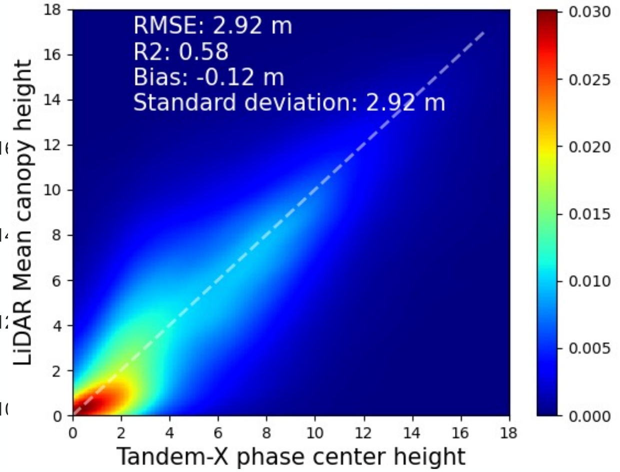
LiDAR mean forest height



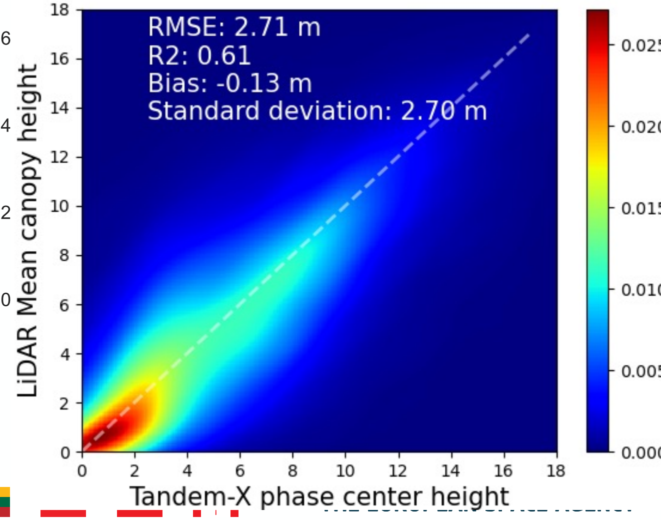
TDX InSAR phase center height



Statistical pixel size ~0.09 ha



Statistical pixel size ~0.81ha

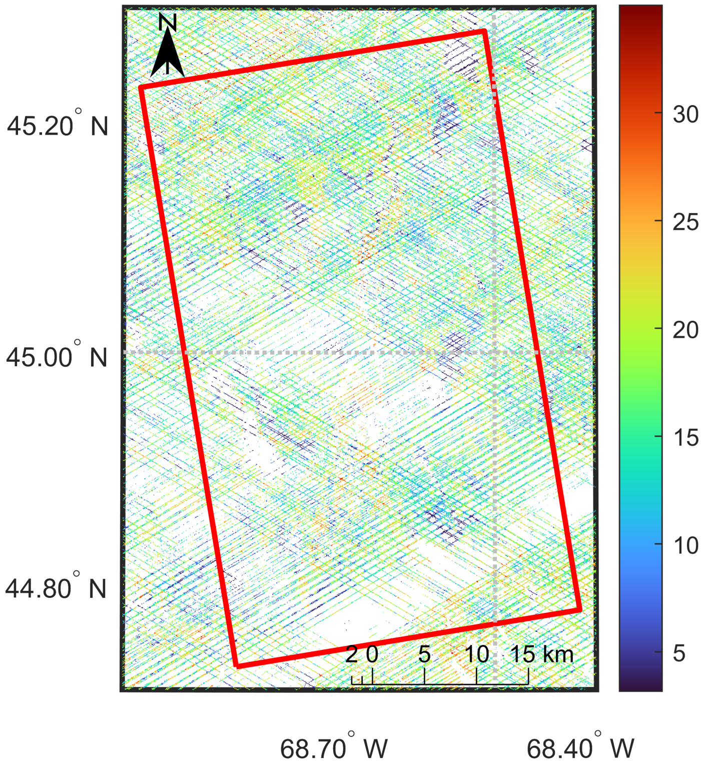


Concluding remarks

- A promising approach in the context of high-resolution spaceborne missions:
  - ✓ Require single-baseline single-polarization InSAR only;
  - ✓ Presenting certain sensitivities to vertical forest structure;
  - ✓ Underlying topography is estimated to an accuracy of ~3.2m at 30m spatial resolution (0.09ha);
  - ✓ A following RVoG based forest inversion achieves an accuracy of ~3.7m at 30m spatial resolution (0.09ha);

- More efforts are still needed:
  - Explore the best use of phase center height for refining the DTM estimates.
  - Analyzing the effects of those factors $(h_v, \lambda, \vartheta, \rho_x, \rho_r \ldots)$ by using ESA TomoSense airborne remote sensing dataset;
  - ……

Thank you for Attention!


N
45.20° N
45.00° N
44.80° N
68.70° W
68.40° W
2 0 5 10 15 km
30
25
20
15
10
5