Mapping 30m Boreal Forest Heights Using Landsat and Sentinel Data Calibrated by ICESat-2

Tianqi Zhang[1] and Desheng Liu[1]

[1]The Ohio State University

November 25, 2022

Abstract

Boreal forest heights are closely associated with the global carbon and energy budget. Existing investigations of boreal forests were mainly carried out at plot scales, which cannot be guaranteed on an annual and regional-scale basis given their sampling schemes. The launch of the Advanced Topographic Laser Altimeter System (ATLAS) onboard the NASA's Ice, Cloud and Land Elevation Satellite (ICESat-2) enables the measurement of forest vertical structure at a global scale. However, with a photon-counting system, ICESat-2 receives substantially reduced signals over vegetated regions (low albedo), making its applications in forest height mapping challenging. This study made the first attempt to develop a 30-m canopy height model (CHM) for a mountainous forested site (located at the north of Fairbanks, Alaska) by coupling the ICESat-2 observed canopy heights, Hcanopy (response), with Landsat-8 (L8), Sentinel-1 (S1) and Sentinel-2 (S2) data using a random forest regressor. Here, Hcanopy corresponds to the 95th percentile (RH95) of all identified canopy photons within a 100-m segment. Before CHM development, low-quality ICESat-2 tracks were filtered out by comparing with the reference airborne lidar considering factors such as slope, canopy cover, signal-to-noise ratio, and canopy height uncertainty. Results suggest that: 1) ICESat-2 Hcanopy has the highest correlation with airborne lidar RH95 under strong beams; 2) the errors of ICESat-2 tracks become larger under lower signal-to-noise ratios (<5), steeper terrain (slope >20@), greater canopy height uncertainty (>0.3) and sparser canopy cover condition (<20%); 3) by adopting the aforementioned criteria in filtering the ICESat-2 tracks, the Pearson's correlation coefficient (R) between ICESat-2 Hcanopy and airborne lidar RH95 has been significantly improved to >0.8 under any beam strength; 4) based on previous results, we find that incorporating features derived from L8, S1 and S2 produces the most desirable CHM (R=0.85), and S2 overall shows a better capability than L8 in predicting regional-scale canopy heights; 5) among all input features, normalized difference vegetation index (NDVI) calculated based on the first red edge band (703.9nm) of S2 is the leading feature on CHM development, whereas land cover appears the least important.

Mapping 30m Boreal Forest Heights Using Landsat and Sentinel Data Calibrated by ICESat-2

Tianqi Zhang, Desheng Liu

Environmental Sciences Graduate Program, The Ohio State University
Department of Geography, The Ohio State University

zhang.9323@osu.edu; liu.738@osu.edu;

ENVIRONMENTAL SCIENCES
GRADUATE PROGRAM

INTRODUCTION

The launch of the Advanced Topographic Laser Altimeter System (ATLAS) on board the NASA's Ice, Cloud and Land Elevation Satellite (ICESat-2) offers a great opportunity to observe forest structures especially at high latitudes (>52°N) (Abdalati et al., 2010). However, ICESat-2's current applications in boreal forest height mapping are still limited at sparse/track level (Neuenschwander et al., 2020). Owing to its adopted photon-counting lidar system, ICESat-2's observations contain high uncertainties over vegetated areas (Neuenschwander and Pitts, 2019), thereby requiring careful pre-processing before being applied to regional-scale canopy height modelling (CHM).

Objectives:

1) Evaluate the efficacy of ICESat-2 observed canopy heights under different scenarios (beam strength, signal-to-noise ratio, canopy cover, canopy height uncertainty, slope);
2) Develop a 30-m regional-scale CHM for boreal forests by integrating sparse ICESat-2 observations (response) with spatially continuous Landsat and Sentinel data.
3) Assess the importance of Landsat- or Sentinel- derived explanatory variables on CHM development.

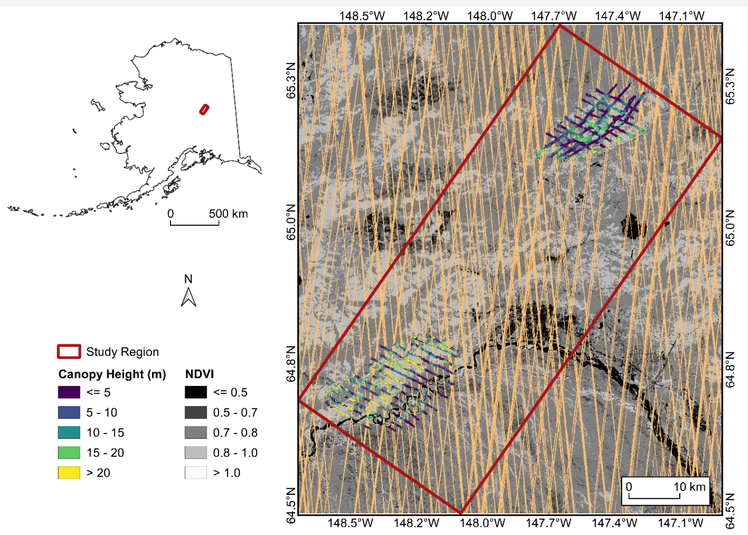
STUDY MATERIALS AND METHODOLOGY

Site location: north side of Fairbanks, Alaska
Validation data: airborne lidar (ALS, 1m), Jul.-Aug. 2014, collected from G-LiHT
Canopy height response: ICESat-2 *Hcanopy* (orange tracks), 2019-2020
Explanatory variables*: 2019

- Spectra (Landsat-8 (L8), Sentinel-2 (S2)), Sentinel-1 polarization (VV, VH).
- L8-/S2- derived: normalized difference vegetation index (NDVI), normalized different water index (NDWI), modified soil adjusted vegetation index (MSAVI), NDVI-derived gray-level co-occurrence texture index
- S1-derived: VVHH (VV/HH), VVH (Li et al., 2020)
- Auxiliary data (AUX): ArcticDEM (elevation, slope, roughness), location (xcoord, ycoord), Copernicus Global Land Service product (land cover, tree fraction)

*All data were resampled to 30m and reprojected to local coordinate system.

Method: random forest regression
Feature selection: remove variables highly correlated (R >0.9) with others meanwhile with lower correlations to ICESat-2 *Hcanopy*.



ACKNOWLEDGEMENT

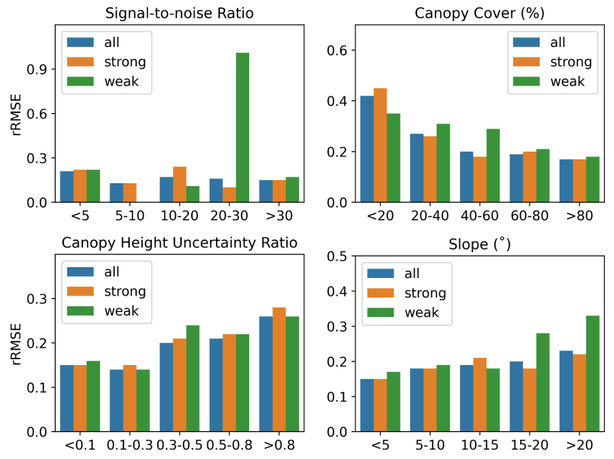
This study was sponsored by the National Science Foundation (#1724786).

EVALUATION OF ICESAT-2 UNDER DIFFERENT SCENARIOS

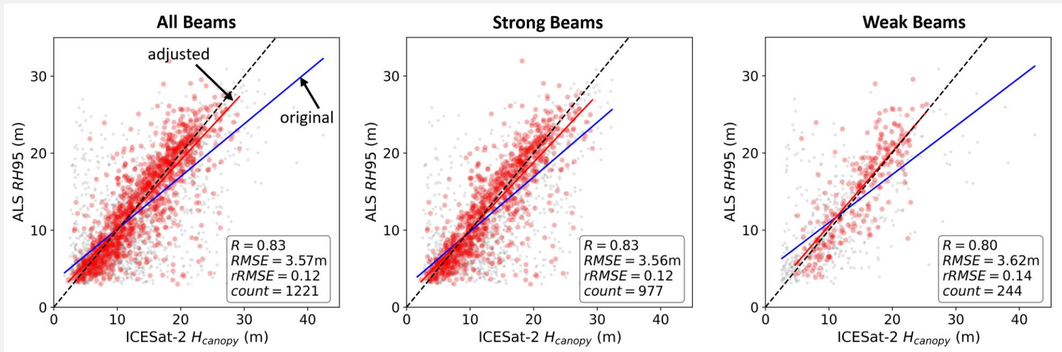
ALS-derived canopy height metrics* vs ICESat-2 *Hcanopy*

	All Beams		Strong Beams		Weak Beams	
ALS	rRMSE	R	rRMSE	R	rRMSE	R
CHmean	0.42	0.60	0.43	0.64	0.42	0.51
RH50	0.39	0.53	0.39	0.57	0.40	0.45
RH75	0.25	0.64	0.26	0.69	0.27	0.55
RH90	0.18	0.69	0.17	0.73	0.20	0.60
RH95	0.16	0.70	0.15	0.74	0.18	0.61
RH98	0.16	0.70	0.14	0.75	0.19	0.61
RH100	0.20	0.68	0.19	0.73	0.23	0.60

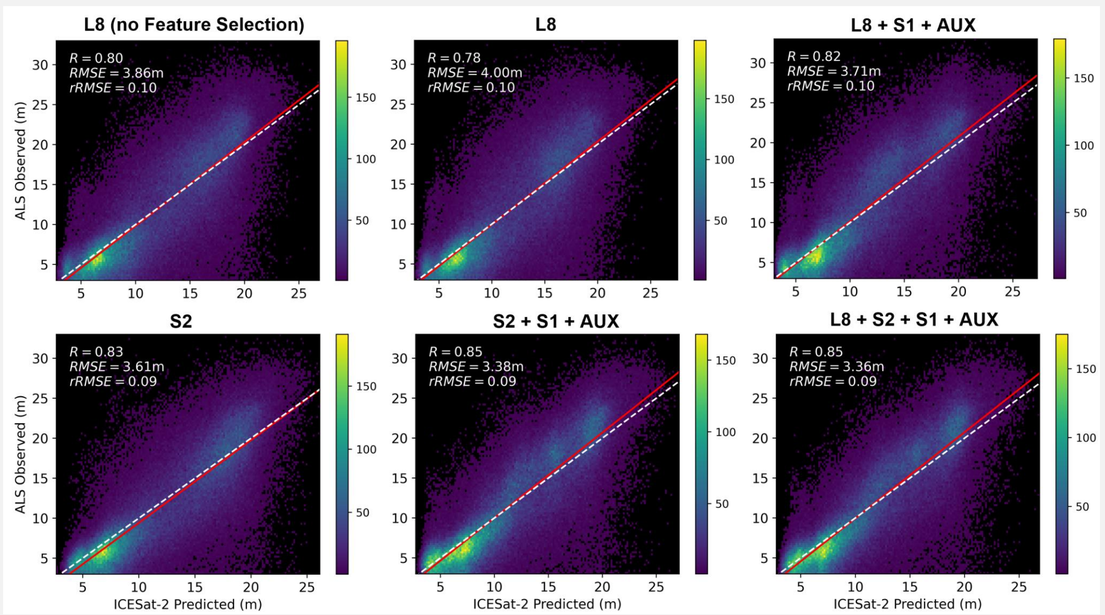
*We locally aggregated the 1m ALS observations to 30m that matches L8's spatial resolution and then computed the percentile canopy heights (listed in the table) from the ALS point clouds within each 30×30m local grid.



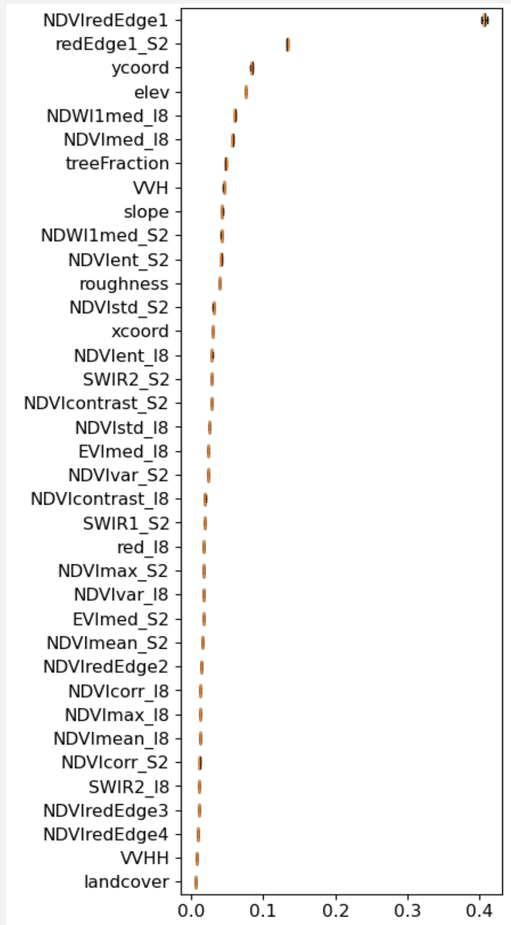
VERTICAL ACCURACY OF ICESAT-2 BEFORE/AFTER QUALITY CONTROL



CANOPY HEIGHT MODELS DEVELOPED BY DIFFERENT FEATURES



FEATURE IMPORTANCE



MAIN FINDINGS

1) The vertical accuracy of ICESat-2 observed canopy heights can be effectively improved with an appropriate quality control regardless of the beam strength.
2) Sentinel-2 derived features achieve better performance than Landsat-8 derived in modelling regional-scale forest heights.
3) NDVI generated from the first red edge band of Sentinel-2 is found the most significant feature in boreal forest height mapping while land cover appears the least important.

REFERENCES

1) Abdalati, et al., 2010. The ICESat-2 Laser Altimetry Mission. Proc. IEEE 98, 735–751.
2) Li, et al., 2020. Developing a method to estimate building height from Sentinel-1 data. Remote Sens. Environ. 240, 111705.
3) Neuenschwander, et al., 2020. Validation of ICESat-2 terrain and canopy heights in boreal forests. Remote Sens. Environ. 251, 112110.
4) Neuenschwander and Pitts, 2019. The ATL08 land and vegetation product for the ICESat-2 Mission. Remote Sens. Environ. 221, 247–259.