Assessing the Accuracy and Influencing Factors of Airborne LiDAR Snow Depth Estimates in Boreal Forests: Insights from NASA SnowEx 2023 Alaska Campaign

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Introduction:

Snowpack plays a critical role in hydrological, ecological, and climatic processes, influencing water resources, energy balance, and ecosystem dynamics. **Accurate, spatially distributed snow depth data is key for understanding snowpack and improving models.** While in-situ measurements are accurate, they cover limited areas and require significant effort. Airborne LiDAR offers a high-resolution alternative with broader coverage. However, differences between LiDAR and ground measurements remain, especially in complex areas like boreal forests. **Factors such as vegetation, terrain, and snowpack properties affect LiDAR accuracy. Identifying these factors is essential to enhance LiDAR-based snow depth estimates.**

Research Questions:

1. How well do airborne LiDAR-derived snow depth measurements correspond with in-situ snow depth observations across boreal forest environments?
2. What are the main environmental factors that affect Lidar measurement errors?
3. Are the factors affecting the error consistent across the different study areas? Which variables are most important in each region?

Data and Methodology:

Data Collection :

- This study utilizes data from the NASA SnowEx 2023 Alaska campaign, focusing on three boreal forest sites: FLCF (Farmers Loop and Creamers Field), BCEF (Bonanza Creek), and CPCRW (Caribou Poker Creek Research Watershed). Airborne LiDAR-derived snow depth and in-situ ground-based snow depth measurements were collected to evaluate LiDAR measurement accuracy.
- Snow-on LiDAR data were collected on March 11, 2023
- Snow-off LiDAR data were collected on Oct 24, 2022
- Snow depth was calculated by ***LiDAR Elevation(Snow_on – Snow_off)***

The following datasets were used:

- LiDAR-derived snow depth: Processed from airborne laser scanning (ALS) data.
- Ground-based snow depth: Measured manually using magnaprobe across multiple plots within each study area.
- Environmental variables: Canopy height, slope, elevation, ground point density, and roughness, extracted from LiDAR point cloud data.

Study Area: NASA SnowEx 2023 campaign

The NASA SnowEx 2023 campaign focuses on understanding snow distribution, snow water equivalent (SWE), and forest-snow interactions in Interior Alaska's boreal forest regions. Three primary study sites were selected for ground-based and airborne remote sensing observations:

1. Bonanza Creek Experimental Forest (BCEF)

•Located 20 km southwest of Fairbanks, Alaska.

•Features lowland floodplains and upland rolling hills with discontinuous permafrost.

2. Farmers Loop and Creamer's Field (FLCF)

•Located in the Fairbanks North Star Borough.

•Situated in a discontinuous permafrost zone with a mix of forested and open areas.

3. Caribou-Poker Creek Research Watershed (CPCRW)

•A 104 km² subarctic research basin northeast of Fairbanks.

•Characterized by complex topography, mixed boreal forests, and permafrost gradients.

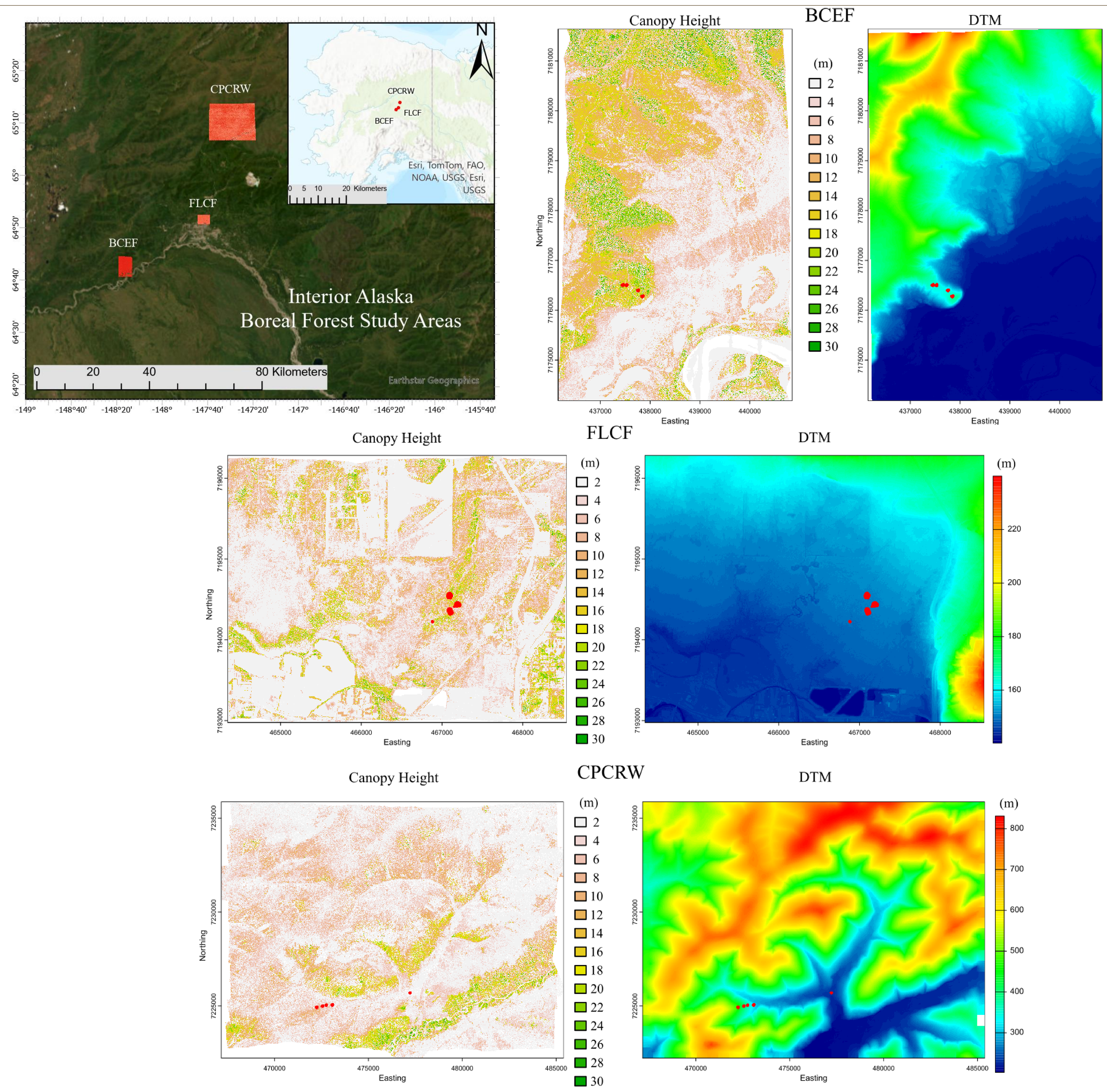
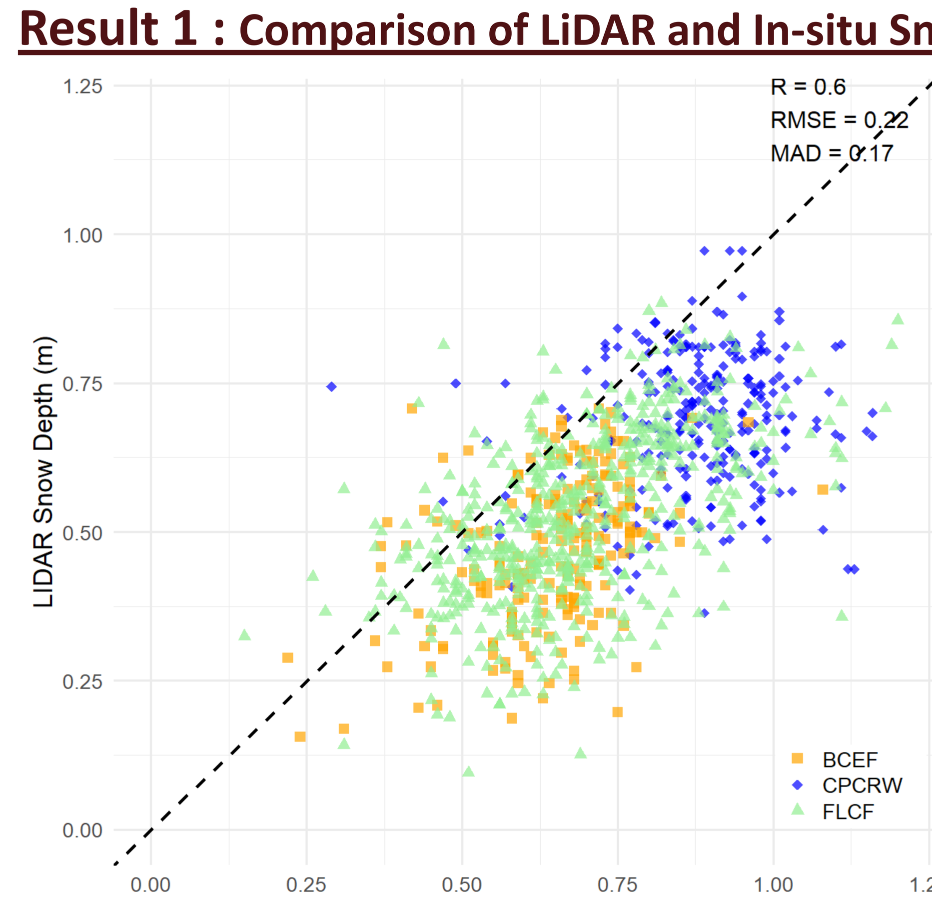


Fig 1 : Study Sites and Environmental Characteristics of Boreal Forest Research Areas in SnowEx 2023

Results:

Result 1 : Comparison of LiDAR and In-situ Snow Depth Measurements:



- The accuracy of LiDAR-derived snow depth was assessed using in-situ measurements from three boreal forest sites (CPCRW, BCEF, and FLCF).
- A Pearson correlation coefficient (R = 0.60) indicated a moderate positive correlation between LiDAR and ground measurements.
- Discrepancies were observed due to environmental factors such as vegetation density and terrain complexity.
- The Mean Absolute Deviation (MAD) was 0.17 m, suggesting notable deviations in certain areas.

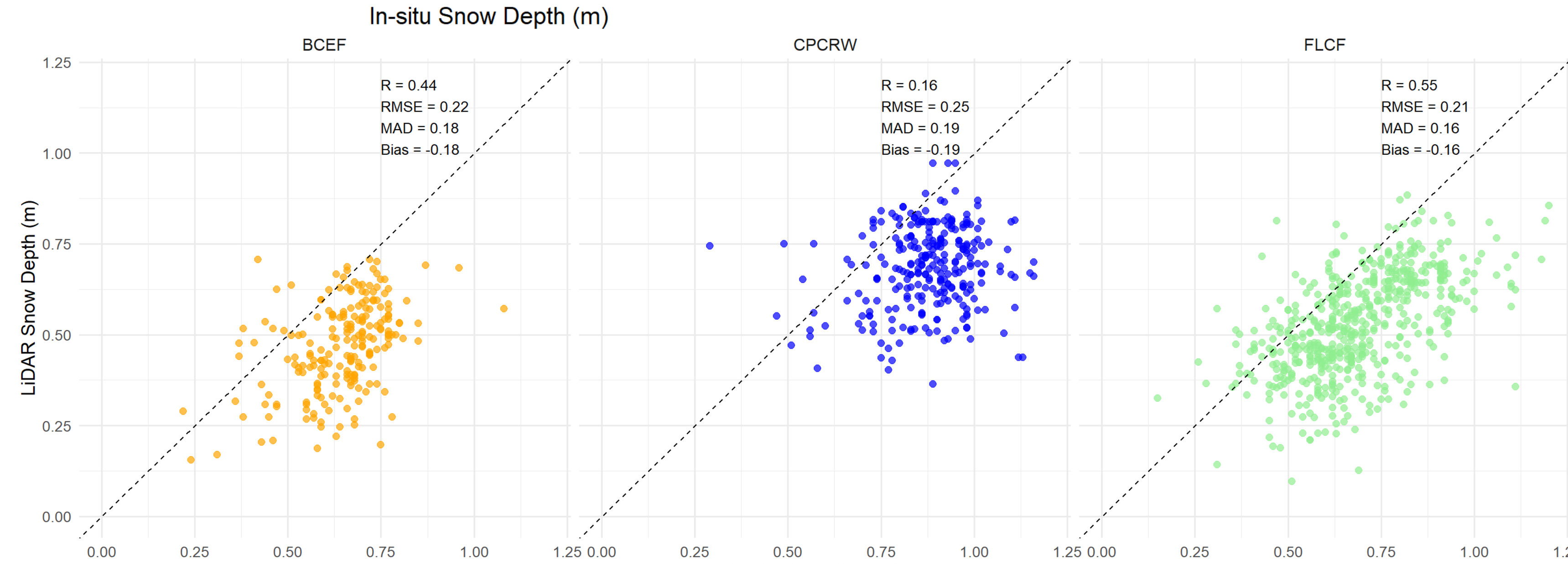


Fig 2 : Evaluation of Airborne LiDAR Snow Depth Accuracy Across Boreal Forest Sites

Result 2 : Key Environmental Factors Influencing LiDAR Snow Depth Errors:

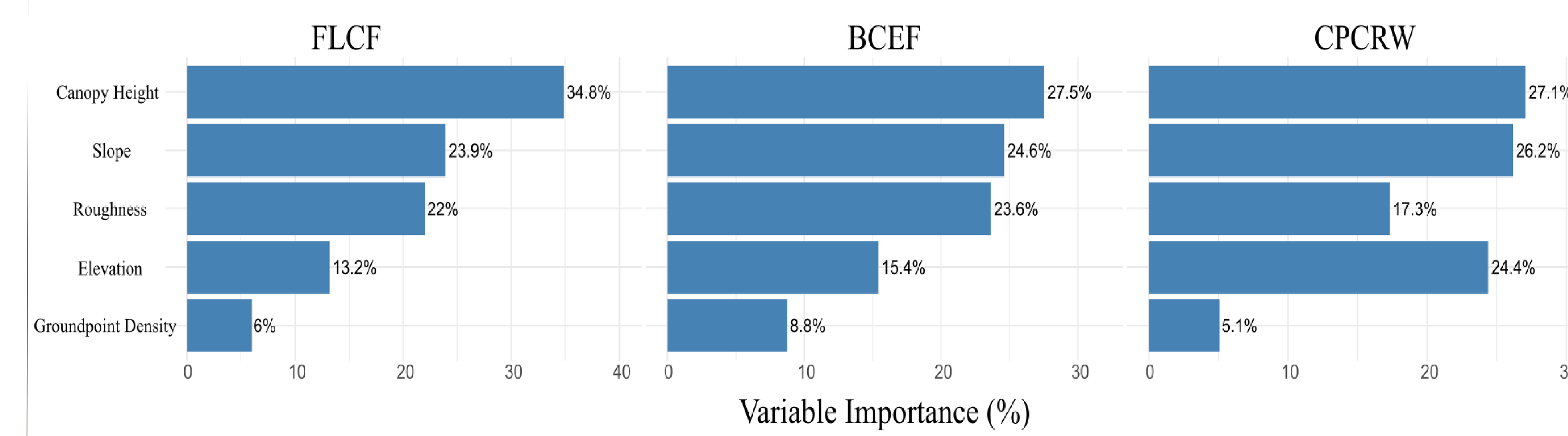


Fig 3 : Key Environmental Factors Influencing LiDAR Snow Depth Error

- Gradient Boosting Machine (GBM) was used to analyze how environmental variables affect LiDAR measurement errors.
- Canopy height was the most influential factor, showing that dense vegetation interferes with LiDAR penetration.
- Slope had a significant impact, especially in steeper terrain.
- Roughness and elevation played secondary roles, still contributing to accuracy variations.
- Ground point density had a relatively minor effect compared to other factors.

Result 3 : Spatial Distribution of LiDAR Snow Depth Errors:

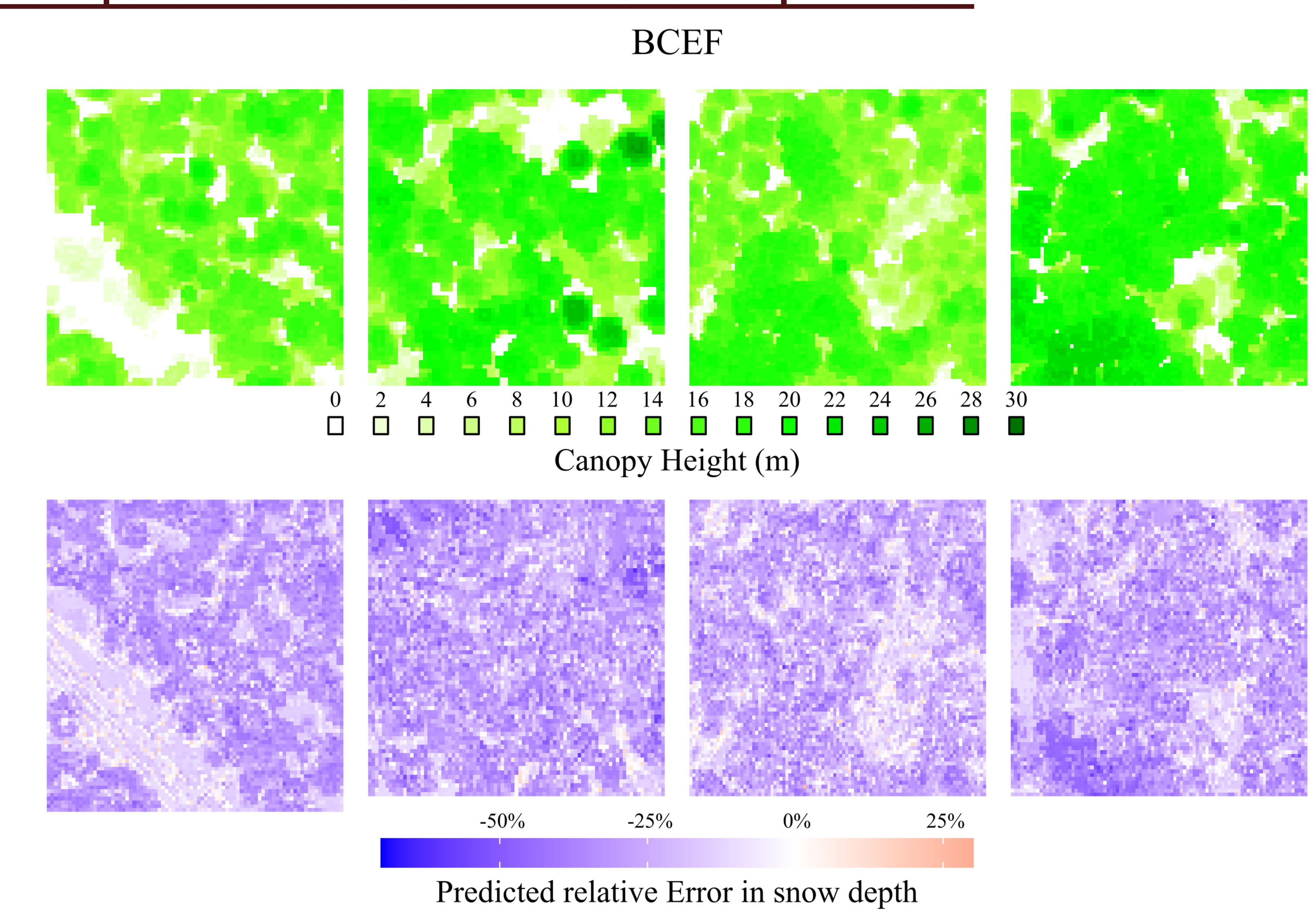


Fig 4 : GBM Predicted LiDAR Snow Depth Errors Across BCEF Region

- GBM was used to generate spatial predictions of LiDAR measurement errors at each study site.
- Higher errors occurred in densely vegetated areas due to reduced LiDAR penetration.
- Moderate to high errors were found in steep slopes, likely caused by terrain-induced distortions in LiDAR returns.
- Lower errors appeared in open field areas, where minimal obstruction allowed for more accurate snow depth estimation.

Conclusion:

- LiDAR-derived snow depth showed moderate accuracy (R = 0.60, MAD = 0.17 m), **with larger errors in areas of dense vegetation and steep slopes.**
- **Canopy height and slope were the most influential factors** affecting measurement errors, while roughness, elevation, and point density played smaller roles.
- The findings demonstrate key environmental drivers of LiDAR error and underscore the value of NASA SnowEx 2023 data for snow depth estimation in forested regions.

Reference :

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