Centre for Satellite Data in Environmental Science (SENSE)

Snowhere to Hide

Detecting Snow in Forests with ICESat-2

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Background

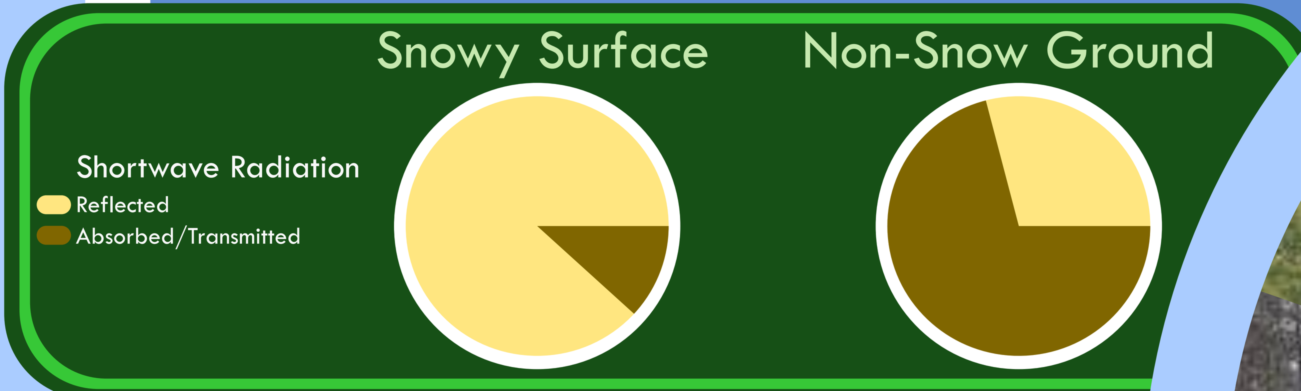
• Snow is an essential climate variable, reflecting significant shortwave radiation from the Earth's surface and storing significant amounts of fresh water during the winter months [1,2].

• Fractional snow cover (FSC) maps are used in a variety of applications, e.g. snowmelt runoff simulation, climate model assessment, and snow cover/duration analysis [3,4,5].

• Existing FSC mapping methods struggle in forested environments because tree canopies obscure the view of the ground from satellite sensors [6]. About 1/5 of the Northern Hemisphere's land is seasonally snowy forest, making this a large-scale problem [7,8].

• Snow intercepted in tree canopies also contributes significantly to the Earth's radiation budget, but it is difficult to model canopy snow processes and the resulting effect on snow albedo [9,10,11].

• There are few ground-based measurements of snow captured in trees, and there are some studies that detect snow with digital cameras, but these are difficult to apply at large scales [12]. There is little research in the use of remote sensing to detect canopy intercepted snow over large areas.



Results

MOD10A1 Fractional Snow Cover

• **Ground Snow Only:** FSC estimates decreased by approx. 0.73% per % canopy cover increase. Cloudy weather or lack of sunlight in winter prevented estimates for almost all Delta Junction dates. Marcell generally had higher canopy cover than Sodankyla, which is a major factor in the fitting process. However, we found that within both sites, the decrease with canopy cover remains statistically significant (-0.61-0.66% per % canopy cover increase).

• **Ground and Canopy Snow:** FSC estimates decrease by approx. 0.32% per % canopy cover increase. The more gradual slope is expected, as more of the visible surface from space is covered with snow

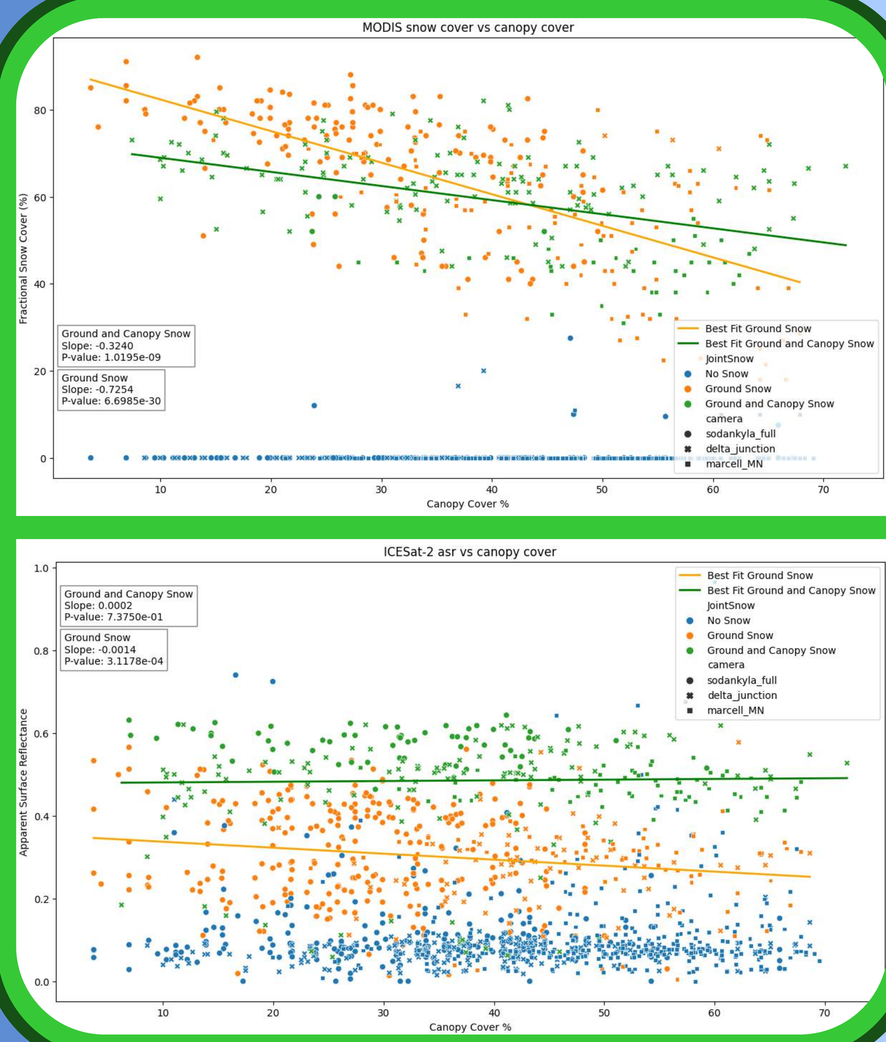
ICESat-2 Apparent Surface Reflectance

Note: We are aware of the limitations of comparing FSC estimates to apparent surface reflectance. We are working on estimating FSC from ICESat-2 data at 500m resolution for a fair comparison. ASR is used as a proxy for the time being.

• **Ground Snow Only:** ASR decreases by 0.0014 per % canopy cover increase. At a glance, ASR seems less affected by canopy cover and the p-value is less significant than MOD10A1 FSC, but it is difficult to make a certain conclusion from this.

• **Ground and Canopy Snow:** The change in ASR with increasing canopy cover is not statistically significant. The ASR is slightly stronger in Sodankyla than Delta Junction at the same canopy cover %. The effect of canopy cover on ASR compared to MOD10A1 seems to be weaker. We hope to confirm this with ICESat-2 based FSC estimates in the near future.

The point of this is that we want to make a fractional snow cover product that is less affected by increased canopy cover so that we can estimate snow cover in forested environments more accurately. The data does not reject the possibility, and further research will provide a clearer picture.

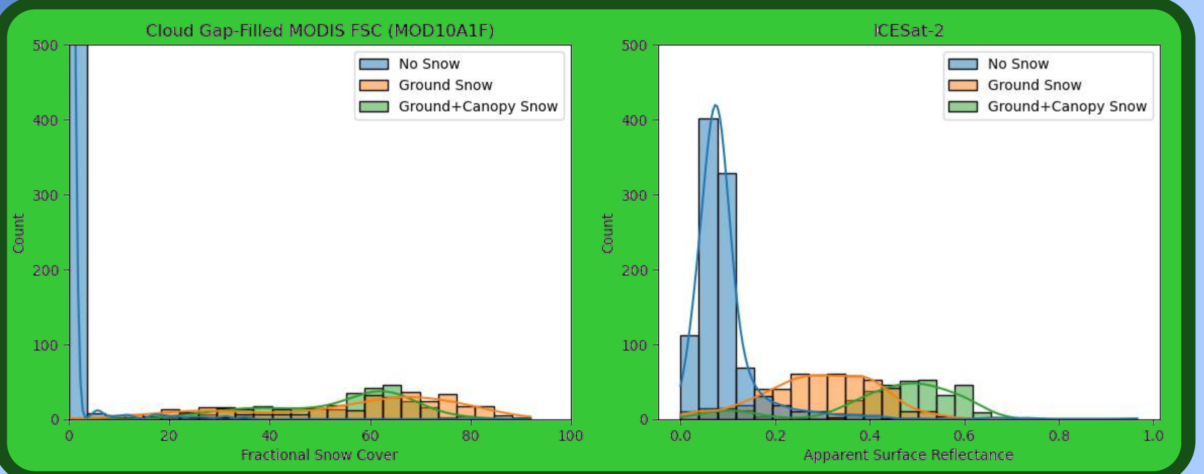


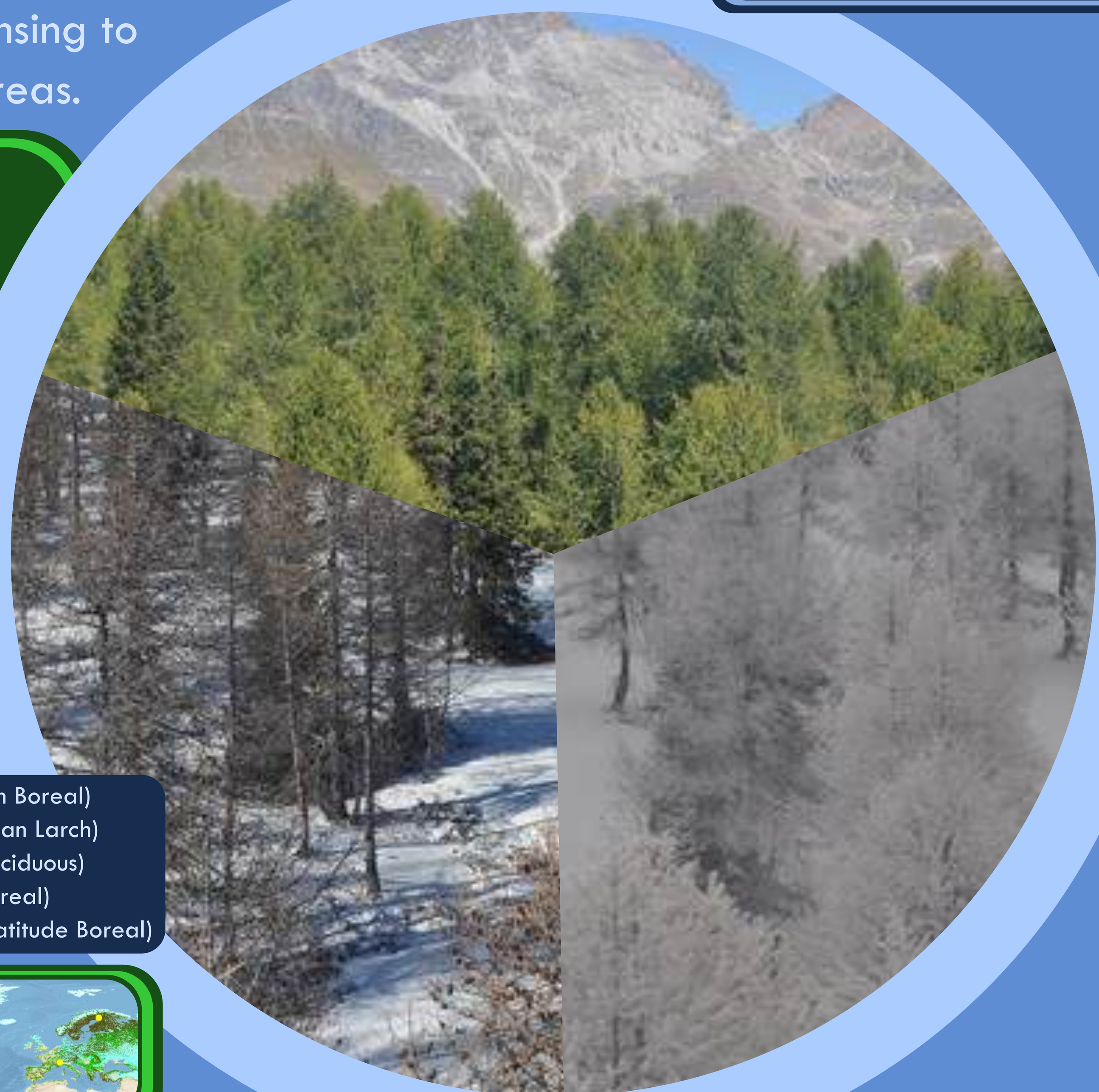
Separation by Snow Conditions

• **MOD10A1:** In theory, when there is snow in the canopy, more of the visible surface from space is covered in snow. Since MOD10A1 estimates FSC as a linear function of NDSI, FSC estimates in these conditions should be higher than when the canopy is snow-free. This is somewhat visible in the plot above when the canopy cover is very high, but not clear. In the left hand plot below, we can see that MOD10A1F snow estimates for Ground Snow vs Ground and Canopy Snow conditions are difficult to separate.

• **ICESat-2 ASR:** The distributions for Ground Snow vs Ground and Canopy Snow are more well-separated in apparent surface reflectance. There is increased overlap with non-snow scenes, making binary snow detection with apparent surface reflectance less accurate than using MODIS NDSI. However, the potential to detect snow in the canopy itself seems to be a lot more promising.

The point of this is that there is some evidence that suggests we can use ICESat-2 radiometry to detect snow in the tree canopy. This could be used towards constraining the contribution of canopy-intercepted snow on the Earth's radiation budget, hence better constrain snow albedo feedback spread in climate models. Further research is needed to investigate the viability of this approach.



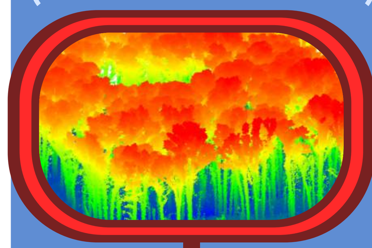


Methodology

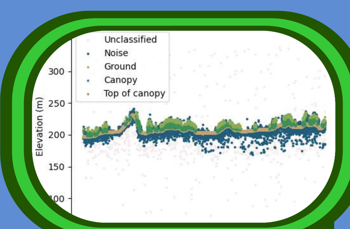
• Unlike passive optical sensors, LiDAR sensors can differentiate between ground and canopy signals.
• Snow is highly reflective at ATLAS's wavelength; we aim to detect it in forests via increased radiometric rates.

• Sodankyla, Finland (European Boreal)
• Torgnon, Italy (Alpine, European Larch)
• Lac Clair, Quebec (N. Am. Deciduous)
• Delta Junction, AK (N. Am. Boreal)
• Marcell, MN (N. Am. Lower Latitude Boreal)

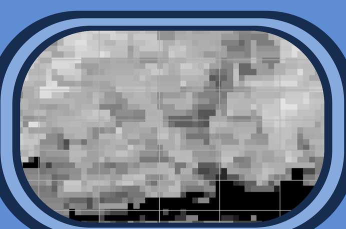
Airborne LiDAR (where available)



ICESat-2 ATL08



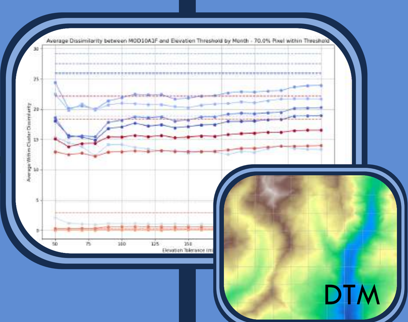
MOD10A1(F) FSC



Phenocam Imagery

Preprocessing

•Within 80m height and 5km [13] of camera
•Ground radiometry, canopy radiometry, canopy height < 100
•Only forested ATL08 segments (Copernicus Land Cover ANC18)
•ATL08 data divided into 500m pixels



MODIS 500m resolution FSC estimates

Manually assessed ground conditions

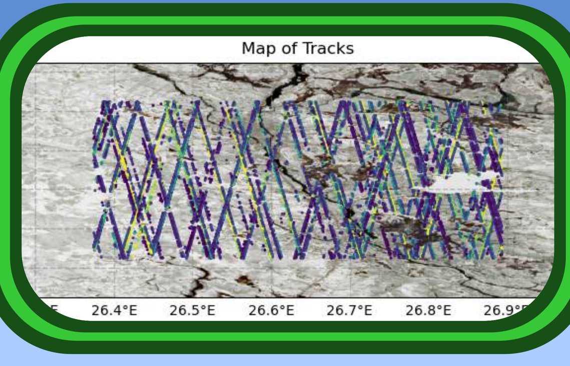
Mean per 500m Pixel

•Apparent surface reflectance
•Ground photon radiometry
•Canopy photon radiometry
•Atmospheric scattering flag
•Canopy cover
• (Future Work) Optical Depth

MOD10A1(F) FSC and ICESat-2 asr

Data as a function of canopy cover

Distribution of data for different snow cover



Conclusions

• Fractional snow cover mapping in forests and canopy snow detection are crucial tasks that existing methods struggle with.

• MODIS-based fractional snow cover (MOD10A1) underestimates snow cover as canopy density increases; future work will explore whether ICESat-2-based FSC is more resilient to this issue.

• Scenes with snow in the canopy show stronger signals in ICESat-2 data compared to those with snow only on the ground, whereas MOD10A1 struggled to distinguish between these scene types.

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