Snow depths in mountainous regions using ICESat-2 and Sentinel-1

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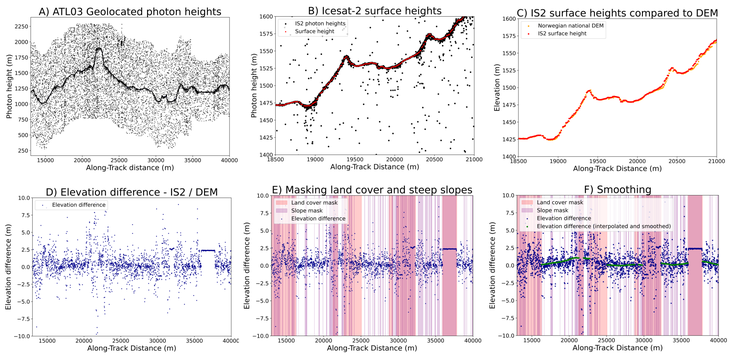
Overview

- Knowledge about seasonal snow accumulation is important for water resource management. However, accurate measurements of snow depth or SWE at a high spatio-temporal resolution are sparse, especially in remote mountainous regions.
- In this study, we retrieve weekly snow depths at 500m resolution using ICESat-2 derived snow depths and Sentinel-1 cross-polarized ratio (CR) over the Southern Norwegian Mountains.
- Snow depths are derived from ICESat-2 ATL03 between January and April for the years 2019-2021. ICESat-2 snow depths are derived by estimating the surface heights based on ICESat-2 ATL03 and comparing it to a high-resolution DEM. For validation, the elevation differences of ICESat-2 and the DEM are compared in snow-free conditions.
- Sentinel-1 CR is derived by calculating the difference in the ratio between the polarization bands (VH/VV) for any given snow day compared to the first snow day of the season. Areas where a worse correlation with snow depths is expected are masked out (forests, water, etc.).
- We apply a multi-temporal sampling method to collect training data based on the spatio-temporal correlation between ICESat-2 derived snow depths and Sentinel-1 CR.
- The ICESat-2 snow depths are used as reference data to calibrate sentinel-1 orbit-specific regression models to retrieve snow depths.

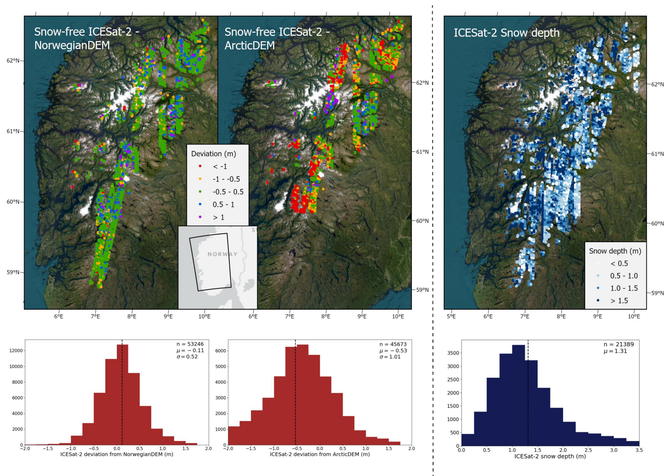
ICESat-2 snow depths

ICESat-2 snow depth pipeline using ATL03 and a reference DEM



ICESat-2 validation

ICESat-2 accuracy assessment in snow-free conditions

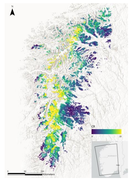


Sentinel-1 CR processing

Sentinel-1 GRD change in backscatter ratio (VH/VV) over time

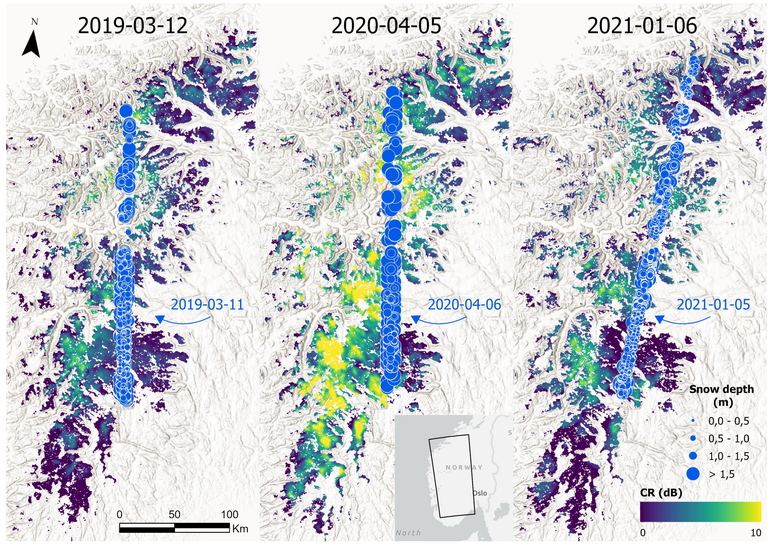
$$CR = (VH_{\text{snow\_day}} / VV_{\text{snow\_day}}) - (VH_{\text{ref}} / VV_{\text{ref}})$$

- Masking (land cover, wet snow)
- Resampling & smoothing



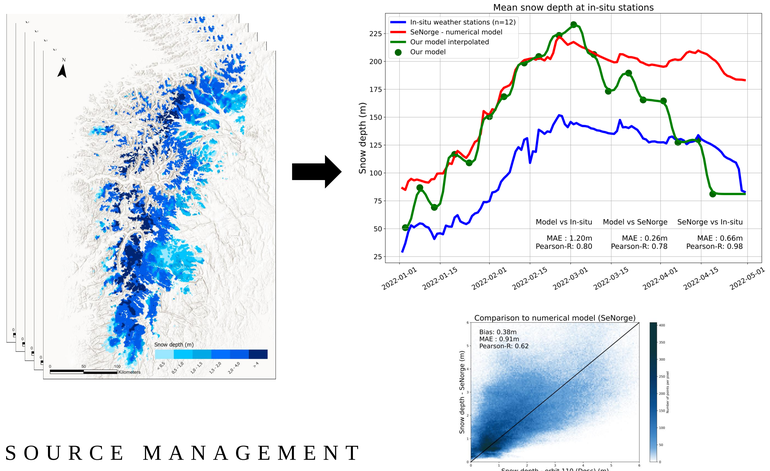
Multi-temporal sampling

ICESat-2 snow depths are matched with the nearest S1 acquisition



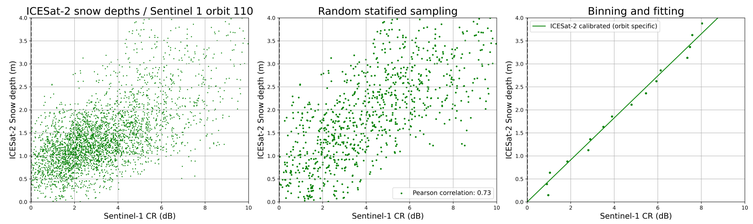
Weekly snow depths over the Southern Norwegian Mountains

Validation against numerical model and in-situ weather stations

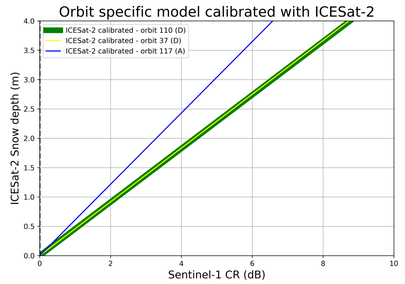


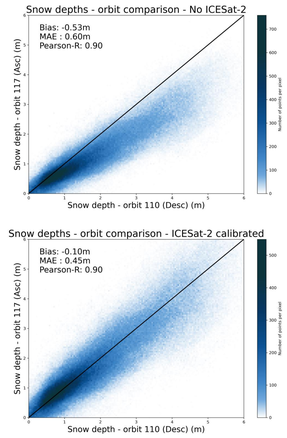
Correlation from multitemporal sampling

Training data strategy



Orbit-specific regression model





Summary

- New insight into the spatio-temporal distribution of snow in remote mountainous regions.
- Results show how ICESat-2 can be used to calibrate orbit-specific Sentinel-1 CR to model snow depth.
- Model has a orbit correlation MAE, Pearson-R and bias of 0.45m, 0.9 and -0.10m using ICESat-2 as calibration.
- Validation at in-situ sites shows a MAE and pearson-R of 0.26m, 0.78 compared to a numerical model and 0.47m, 0.79 compared to in-situ stations.
- The difference between the station and nummerical model makes it difficult to validate the results properly.
- The method is limited to deep snow (>0.5 m) and is affected by changes to the snowpack composition as it relies on C-band SAR.
- The method is limited to certain land cover types due to the nature of the C-band and ICESat-2.
- Using the right sampling method, you can model snow depths based only on freely available satellite data and a reference DEM.
- The method is scalable to other regions of the world where a suitable reference DEM is available, or polar regions with ICESat-2 repeat-tracks.

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