Leveraging Earth observations to model snow cover dynamics over Scandinavia

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Abstract

Snow cover exerts a profound influence on biogeophysical and biogeochemical processes at the land-atmosphere interface by regulating surface energy, water, and carbon balance. However, the dynamic nature of snow presents a significant challenge in accurately depicting its behavior in models due to its high spatiotemporal variability. Consequently, enhancing the representation of snow cover dynamics in Earth System Models (ESMs) relies heavily on the precision and comprehensiveness of observational datasets utilized for model validation and calibration.

Satellite imagery offers a long-term record that aids in monitoring changes in snow cover dynamics across larger areas, while emerging drone and terrestrial imaging technologies provide higher resolution data for specific regions. This complementary information derived from spaceborne, airborne, and terrestrial Earth observations is invaluable for gaining a deeper understanding of the complex processes within the climate system.

Here, we introduce a new regional fractional snow-covered area (fSCA) data from MODIS. We also show how this data can be used to evaluate the Community Land Model (CLM5) and to calibrate Flexible Snow Model (FSM2) using the Multiple Snow data Assimilation System (MuSA).

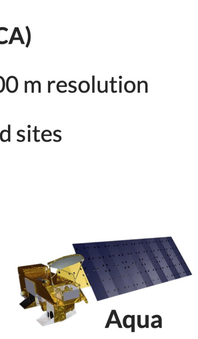
Snow cover phenology from MODIS

Cloud-free fractional snow-covered area (fSCA)

- Daily fSCA maps over Scandinavia at 500 m resolution
- Time series of fSCA values over selected sites

Annual snow phenology metrics

- Snow cover duration (SCD)
- Fractional snow cover duration (fSCD)
- Consecutive snow cover day (CSC)
- Cloud persistence count (CPC)
- First snow day (FSD)
- Last snow day (LSD)
- Snow seasonality index (SSI)



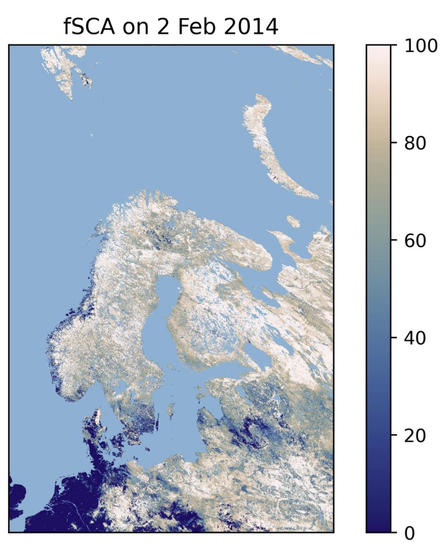
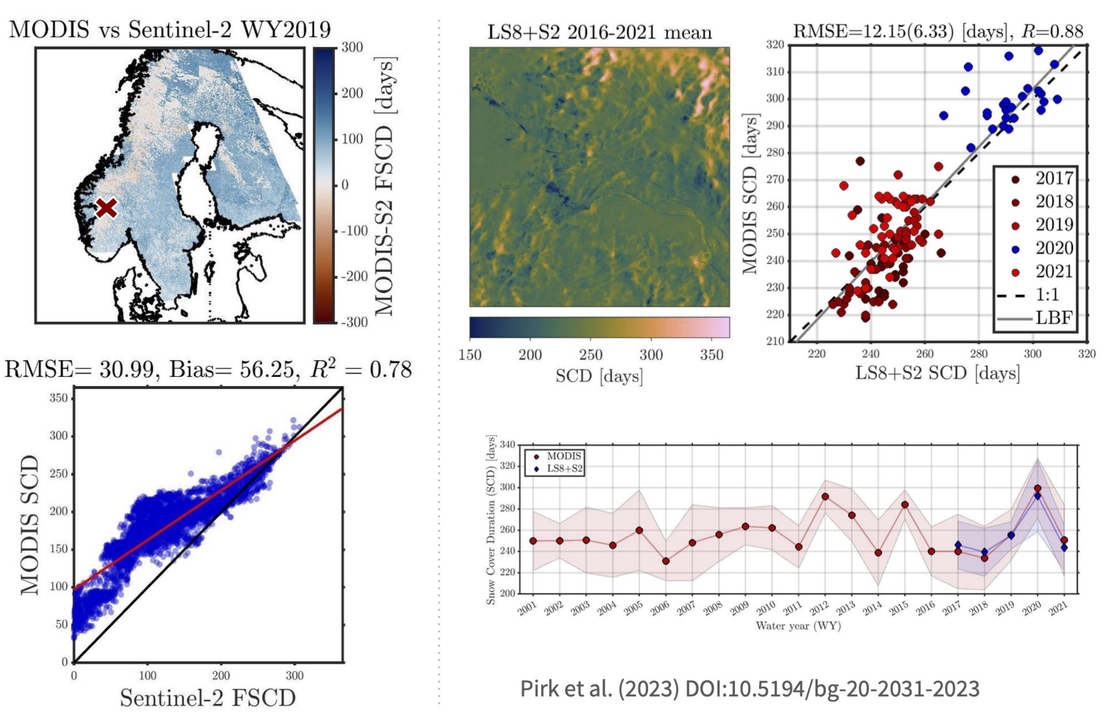


Figure 1: Snow metrics were calculated through water year (from 1 Sep to 31 Aug) based on fSCA values from MODIS (combined MOD10A1 and MYD10A1 v6.1)

How accurate are the MODIS retrievals? :

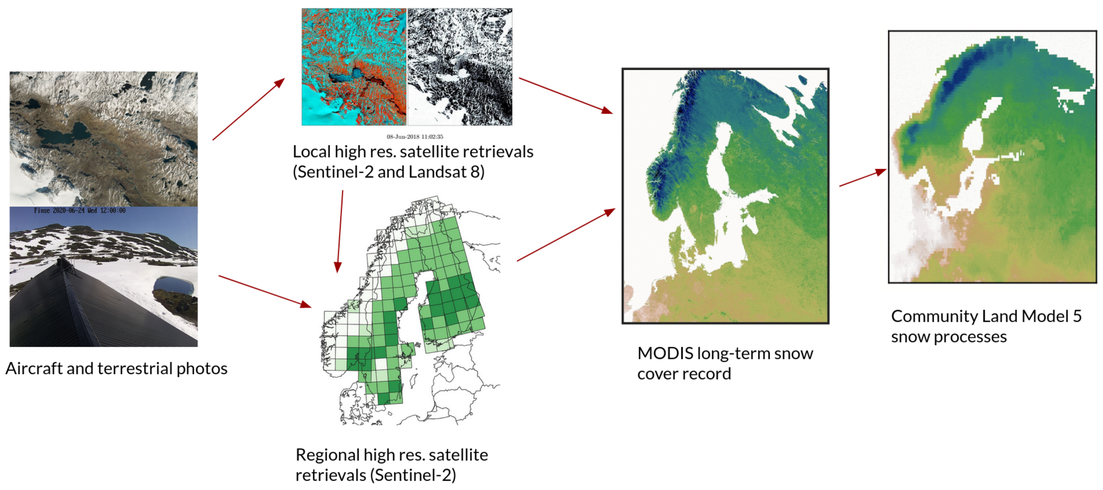


Pirk et al. (2023) DOI:10.5194/bg-20-2031-2023

Figure 2: Validation of MODIS regionally over Fennoscandia (left) and locally over Finse (right) by using high resolution Earth observations.

Integrating Earth Observations with Earth System Modeling:

Understand and improve snow process representation in CLM5 at regional scale using representative validation data from satellite remote sensing



Acknowledgments

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We gratefully acknowledge the use of several freely available data sets : **MERRA-2** Land Surface Diagnostics from NASA GES DISC. **ERA5** and **ERA5-Land** hourly data on single levels from Copernicus Climate Change Service Climate Data Store (CDS). **MODIS** daily snow cover from NSIDC. **Landsat 8** scenes were downloaded from USGS Earth Explorer. **Sentinel-2A/2B MSI** scenes over Finse were obtained from the Copernicus Open Access Hub. **Sentinel-2** snow cover retrievals were obtained from Copernicus High Resolution Snow and Ice Monitoring Service.

Evaluation of a land surface model (CLM5)

Motivation : Evaluation of the land surface model of NorESM2 and CESM2, namely CLM5, for snow cover dynamics

Two CLM5 experiments were conducted over the Scandinavian region.

- ▶ Regional simulation at 0.25° resolution
- ▶ Two atmospheric forcing data sets : GSWP3 (default) and ERA5
- ▶ Simulation period : 2000-2014 (GSWP3) and 2001-2020 (ERA5)

Table 1: Several reanalyses were used to benchmark the performance of the CLM5 experiments.

Climate Reanalysis	Spatial Res.	Temporal Res.	Temporal Coverage	Source
ERA5-Land	0.1°	Hourly	01/1981-present	ECMWF
ERA5	0.25°	Hourly	01/1950-present	ECMWF
MERRA-2	0.5° x 0.625°	Hourly	01/1980-present	NASA-GMAO
Satellite (product name)	**Spatial Res.**	**Temporal Res.**	**Temporal Coverage**	**Source**
Terra (MOD10A1)	500 m	Daily	24/02/2000-present	NASA
Aqua (MYD10A1)	500 m	Daily	04/07/2002-present	NASA
Sentinel-2 (L2)	10-20 m	5 days	23/06/2015-present	ESA
Landsat 8 (L2)	30 m	16 days	11/02/2013-present	NASA/USGS

CLM5 and reanalyses vs. MODIS snow cover duration :

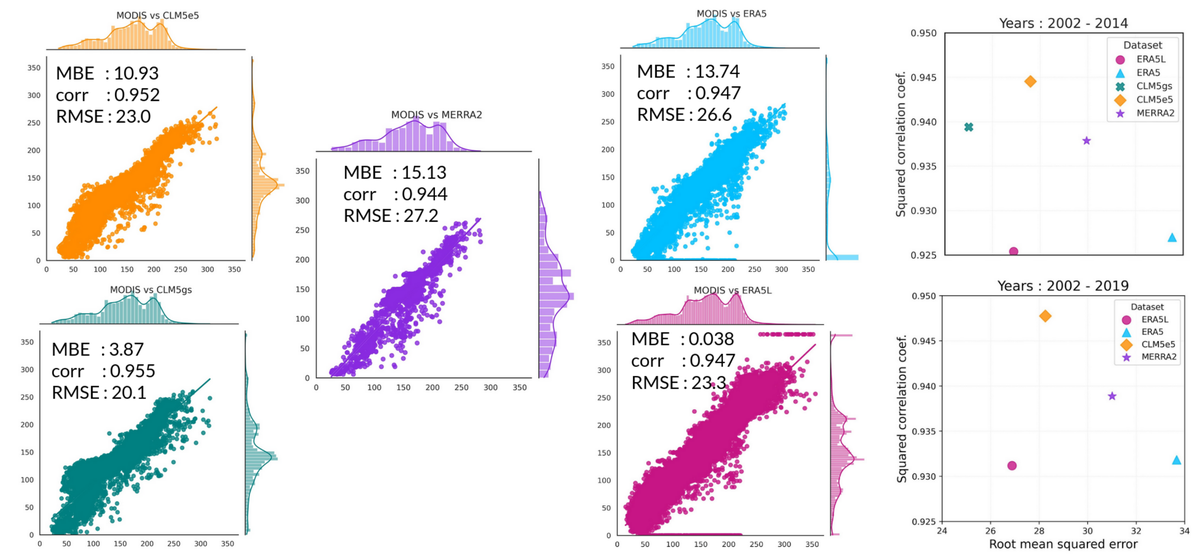

Figure 3: Scatter plots of snow cover duration for 2014 from ERA5-Land, ERA5, and MERRA-2, respectively, versus MODIS. The last column shows evaluation metrics for each data set averaged over all years.

Snow data assimilation with MuSA

Motivation : Understanding the response of snowmelt rate and streamflow to climate change in Hardangervidda, Norway

The Multiple Snow data Assimilation System (MuSA; Alonso-González & Aalstad et al. (2022) DOI:10.5194/gmd-15-9127-2022)

- ▶ Ensemble of regional snow simulations at 1 km resolution
- ▶ Topography-based downscaling of atmospheric forcing data (ERA5)
- ▶ Simulation period : 2000-2020 (reference) and 2036-2055 & 2076-2095 (future, pseudo warming based on RCP8.5)

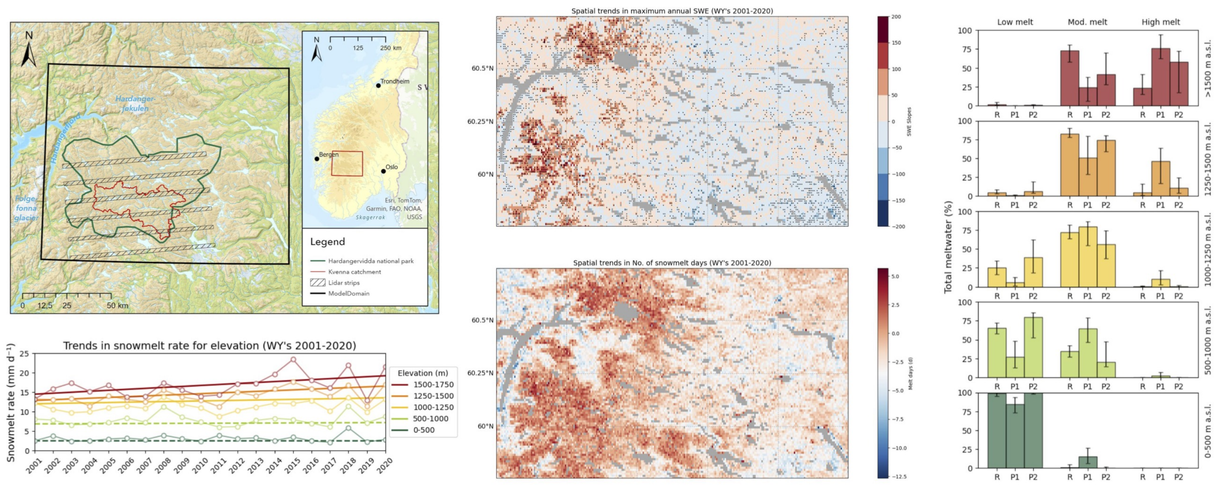

Figure 4: Temporal (left) and spatial (middle) trends in snowmelt rates for different elevation bands. Total meltwater amount (right) at different melt rates for reference and future periods.