An Ensemble-based Subgrid Snow Data Assimilation Framework

Kristoffer Aalstad[1]*, Sebastian Westermann[1] and Laurent Bertino[2]

[1]Section for Geography and Hydrology, Department of Geosciences, University of Oslo, Oslo, Norway

[2]Nansen Environmental and Remote Sensing Center, Bergen, Norway

*Presenting author, contact: kristoffer.aalstad@geo.uio.no

Funded by The Research Council of Norway as part of the SatPerm project

1. Introduction

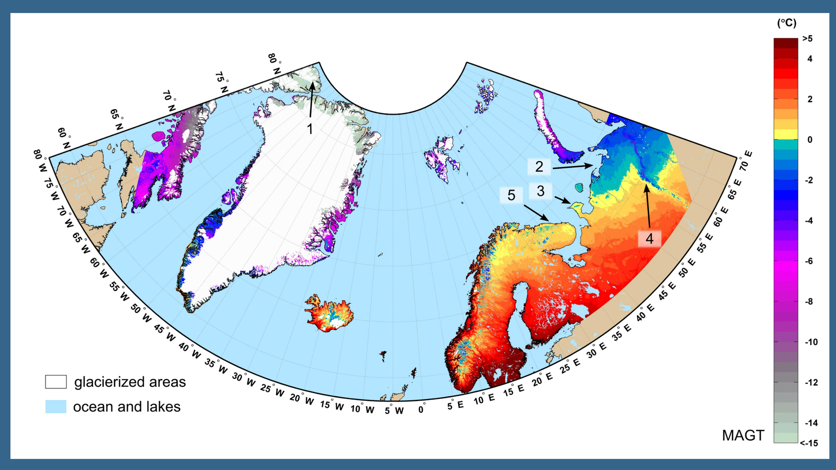


Figure 1: Estimated mean annual ground temperature map of the North Atlantic permafrost region (adapted from [3]). Developed using an equilibrium model using direct insertion of MODIS-LST and ERA-Interim forcing. Through ESSDA we wish to build on this approach for satellite based snow and permafrost mapping.

- Snow strongly modulates the near surface energy and water balance.
- Still, both model estimates and satellite retrievals of snow depth distributions are highly uncertain.
- To constrain this uncertainty we are developing a modular and robust ensemble-based subgrid snow data assimilation framework (ESSDA).

2. Snow Model

- Physically based, cheap and recursive implementation of the subgrid snow distribubtion submodel (SSNOWD; see [1]).
- Assumes that pre-melt subgrid scale snow distributions (SSDs) are lognormal and that melt is homogeneous.
- Snow cover fraction (SCF) is recovered by evaluating the cumulative distribution at the current melt depth.

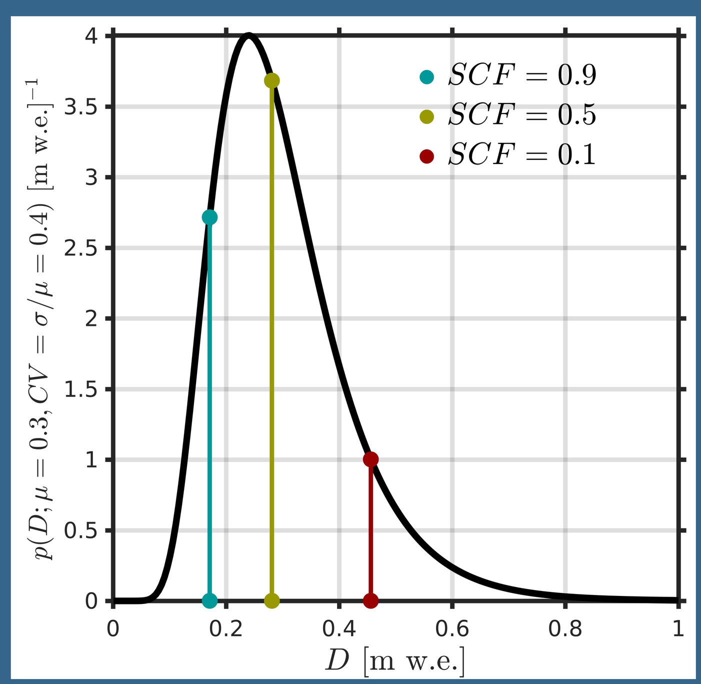


Figure 2: Typical lognormal pre-melt SSD (black) with a mean depth of 0.3 [meters water equivalent] and a coefficient of variation (CV) of 0.4. Vertical lines show the melt depths (absissca) corresponding to 90%, 50% and 10% SCF.

3. Observations

Figure 3: View of the study site, the Bayelva catchment (encircled in yellow), from Schetteligfjellt near Ny Ålesund (79 N), Svalbard, Norway. The photograph was taken by the presenting author on the 07.05.2016.

- Assimilation: Space-borne SCF retrievals from MODIS and (in the pipeline) LandSat8.
- Validation: Ground-based SCF retrievals from images taken by an automatic camera system along with spatialy distributed snow depth surveys in the Bayelva catchment.

4. Data Assimilation Framework

- ESSDA employs the deterministic ensemble Kalman filter (DEnKF) with Gaussian anamorphosis for joint state and parameter estimation as in [2], but with analytical anamorphosis functions.
- State vector containing the SCF (directly observed) augmented by the mean and CV of the pre-melt SSD.
- In the anamorphosis we use a logit transform for the SCF and CV (both double bounded) and a log transform for the pre-melt mean snow depth (lower bound of 0).
- Both additive inflation and the DEnKF analysis step are carried out in the transformed space.

Acknowledgements

- Our research has been conducted within the 'SatPerm' project funded by the Research Council of Norway and is associated with the NordForsk funded Noric Centre of Excellence 'EmblA'. The background is a LandSat8 falsecolor image of North-Western Svalbard (taken 28.05.2013, courtesy USGS/NASA).

References

[1] Liston, G.E. (2004). Representing Subgrid Snow Cover Heterogeneities in Regional and Global Models. Journal of climate. 17(6):1381-1397.

[2] Simon, E and Bertino, L. (2012). Gaussian anamorphosis extension of the DEnKF for combined state parameter estimation: Application to a 1D ocean ecosystem model. Journal of Marine Systems, 89:1-18.

[3] Westermann, S et al. (2015). A ground temperature map of the North Atlantic permafrost region based on remote sensing and reanalysis data. The Cryosphere, 9:1303-1319.

5. Synthetic Experiments

- We conducted a series of synthetic (twin) experiments using a smooth SCF depeltion as truth. These allowed us to test the sensitivity of ESSDA to the error model, number of ensemble members, observation frequency and parameter initialization.

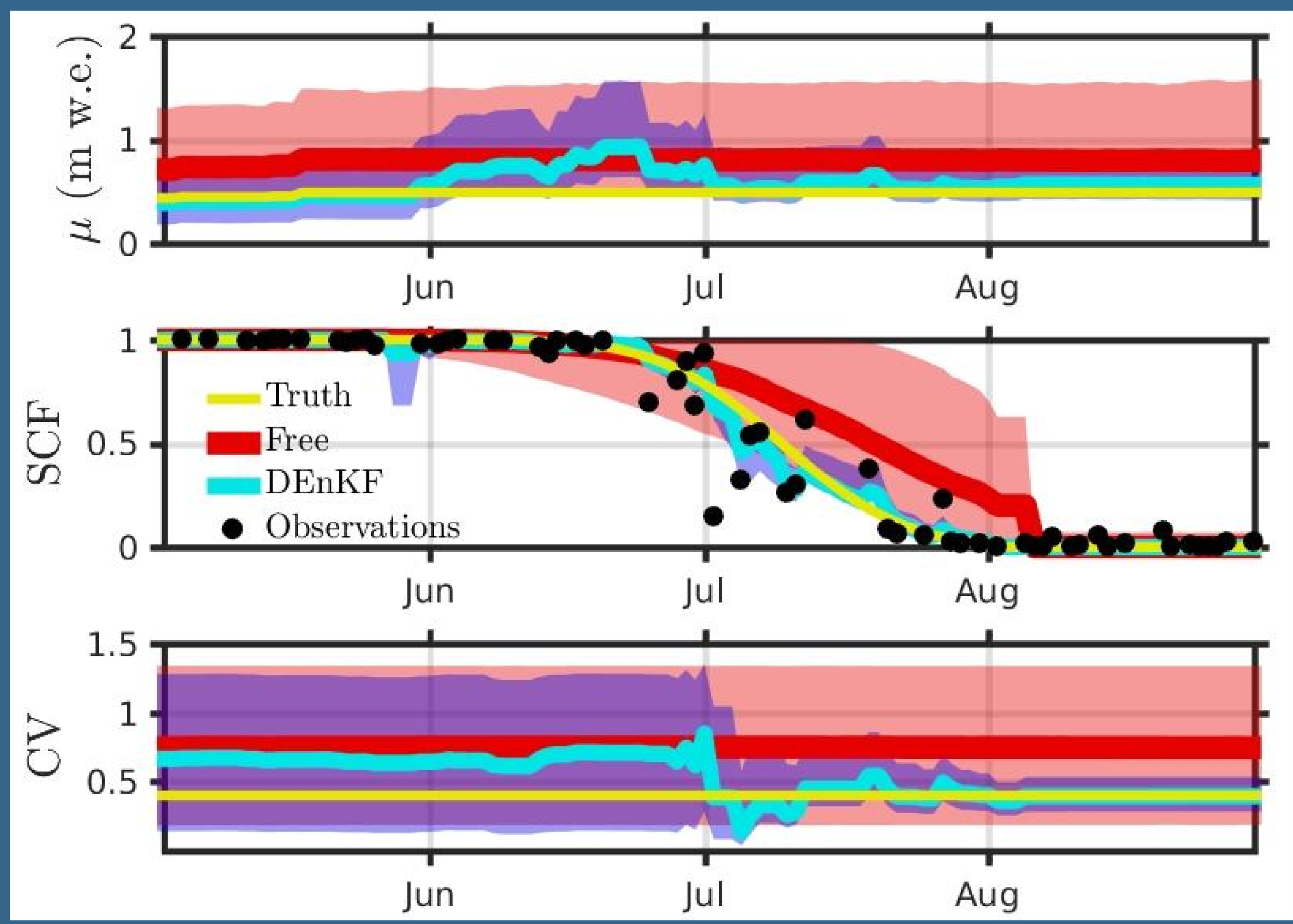
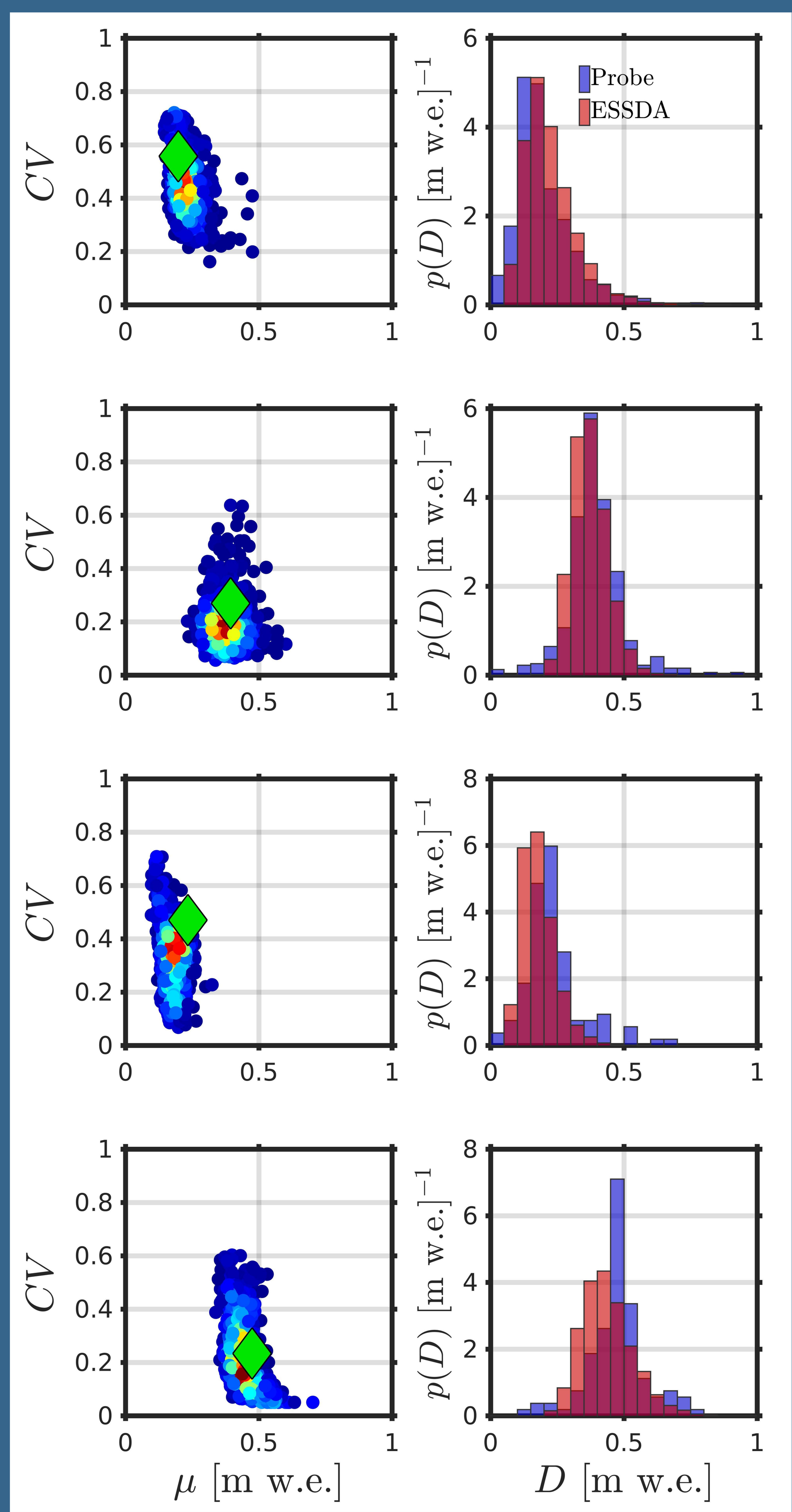


Figure 4: Example of a synthetic truth (yellow) from which noisy observations (black dots) and forcing is generated. Panels (top to bottom) show the pre-melt mean snow depth, SCF and CV. The red and blue lines and corresponding shading show the median and 95% central range of the unconstrained (free; no DA) and ESSDA (DEnKF) ensemble (N=1000) respectively.

6. Real Experiments



- An ensemble (N=1000) of SSNOWD realizations are forced by perturbed and downscaled ERA-Interim reanalysis data and constrained by MODIS SCF retrievals (MOD10A1 and MYD10A1 v06) using the DEnKF (see 4.) for a 1 km² domain in the Bayelva catchment for four hydrological years.

Figure 5: Evaluation of ESSDA estimates of the pre-melt SSDs at Bayelva for the (top to bottom) 2008, 2009, 2013 and 2014 snow seasons. Left panels: The set of parameters (mean and CV) for the ensemble of estimated pre-melt SSDs (reds indicate a clustering of ensemble members) along with the distribution parameters estimated by snow probe surveys (green diamonds). Right panels: Histograms of the pre-melt SSDs corresponding to the ensemble median parameter estimates from ESSDA (red bars) and that sampled by in-situ snow probe measurements at fixed (but randomly selected) locations within the catchment (blue bars).

7. Summary

- Through ESSDA we present a simple and modular approach for snow state and parameter estimation. By making use of an ensemble of non-linear snow depletion curves and Gaussian anamorphosis we can move away from using coarse-scale and biased passive microwave snow depth retrievals to fine-scale shortwave reflectance based snow cover retrievals in constraining our snow model. Consquently, our framework offers the potential for subgrid snow depth distribution estimation at the kilometer scale useful for permafrost mapping, satellite-era snow reanalyses and hydrometeorological forecast initialization.