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Modelling of glacier surface mass balance with assimilation of glacier mass balance and snow cover observations from remote sensing

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In order to assess past and future glacier mass changes best we need to combine models with in-situ observations and remote sensing observations, whose availability is rapidly increasing. We explore the possibilities of data assimilation of these observations in a glacier model to assess glacier mass changes.

We use the assimilation of in-situ measurements and remote sensing observations to model the surface mass balance (SMB) of western Svartisen, an ice cap in northern Norway. The in-situ measurements consist of point observations that directly measure surface mass balance by determining accumulation snow and ablation of snow and ice twice a year from stakes drilled in the ice. The Engabreen catchment of this ice cap is one of the most studied glaciers in Norway, such that large number of in-situ mass balance observations is available for this part of the ice cap. In addition, there are less frequent in-situ observations for the Storglombreen catchment. To complement the in-situ point observations we also include remote sensing of the snow cover extent that provides information with good spatial distribution over the entire ice cap. The snow cover extents are derived from Landsat imagery that provide snow cover extend on a 30 m resolution on two-week intervals at best depending on cloud cover.

The observations are assimilated into a model that computes the SMB using a simplified energy balance to determine the ablation. This approach makes use of two model parameters to estimate the temperature-dependent surface energy fluxes. We estimate these two model parameters and the spatially variable precipitation bias. Our problem is particularly challenging as snow cover fraction is doubly bounded in physical space. In an attempt to alleviate this issue we make use of the technique of Gaussian anamorphosis in the analysis step.

Firstly we compare the performance of three assimilation techniques, Ensemble Kalman filter, Ensemble Smoother, and Ensemble Smoother with Multiple Data Assimilation (ES-MDA), with twin experiments. The ES-MDA provides the best reconstruction of the model parameters compared to a pre-defined truth. In a next step, we apply the ES-MDA on the ice cap with real observations for the period 1960 to 2016. Using the ensemble we assess the uncertainty in the estimated mass balance and we compare the modelled mass balance with independently observed geodetic mass balance to determine to what extent the assimilation of in-situ and remote sensing observations improve the modelled mass balance.