Multi-scale assimilation of AMSR-E snow water equivalent and MODIS snow cover fraction observations in northern Colorado

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Snow estimation in the Rocky Mountains is crucial to water supply in the Western United States. Satellite-based snow observations from two distinct sensors are used in an assimilation framework to analyse their benefit for fine-scale snow state estimation. Eight years (2002–2010) of Advanced Microwave Scanning Radiometer–EOS (AMSR-E) snow water equivalent (SWE) retrievals and Moderate Resolution Imaging Spectroradiometer (MODIS) snow cover fraction (SCF) observations are assimilated separately or jointly into the Noah land surface model over a domain in Northern Colorado. The results are validated against in situ observations at 14 high-elevation Snowpack Telemetry (SNOTEL) sites with typically deep snow and at 4 lower-elevation Cooperative Observer Program (COOP) sites.

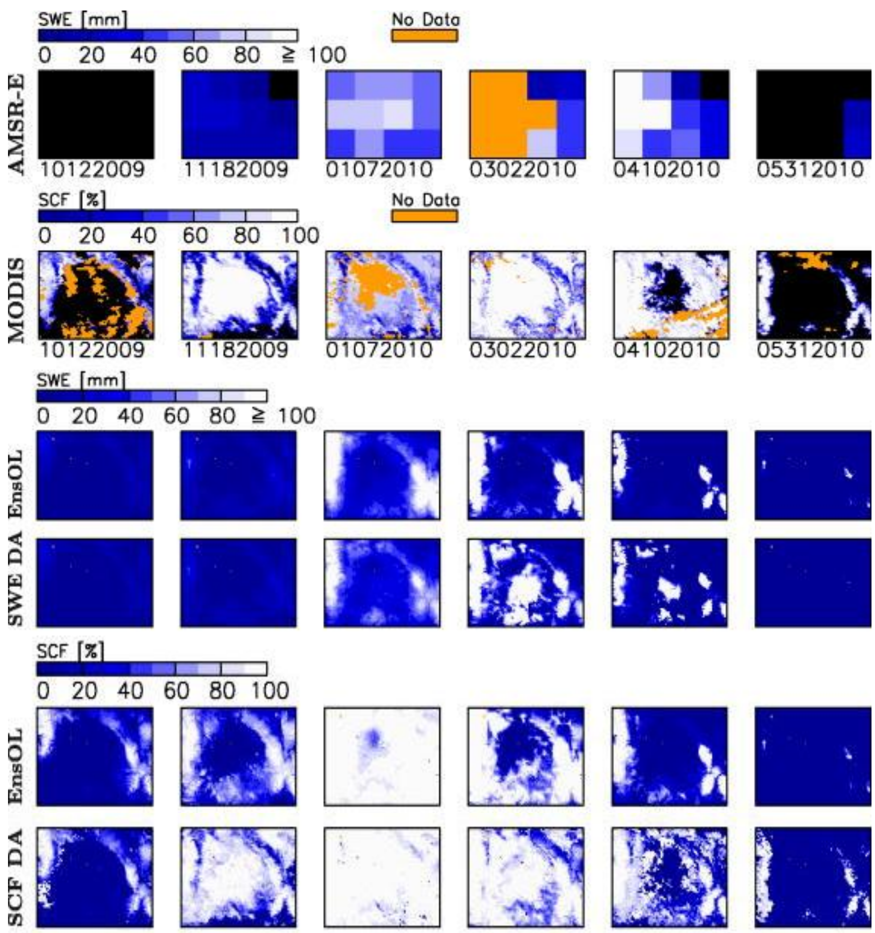

Figure 1: SWE (at 08:00 UTC) and SCF (at 17:00 UTC) fields for 5 days (MMDDYYYY) in the winter of 2009–2010. No snow is indicated as black. The top 2 rows show SWE and SCF satellite observations. The remaining rows show SWE (at 09:00 UTC) and SCF (at 18:00 UTC) for the Ensemble Open Loop (EnsOL) forecast and the analyses obtained through data assimilation (DA) of SWE or SCF without a priori scaling.

The nature of AMSR-E and MODIS snow observations is illustrated in Figure 1 for one snow season. AMSR-E retrievals are coarse-scale (25 km) SWE estimates, with data missing when the swath does not cover the study area. To estimate the snow at a fine model scale (1 km), we applied a distributed ensemble Kalman filter, which allows (i) downscaling the coarse-scale observations to the fine scale and (ii) propagating observed observations to unobserved areas, thus enabling smooth fine-scale SWE estimates. MODIS provides fine-scale estimates of SCF (not SWE), but only over cloud-free areas. To assimilate this indirect snow information, a snow depletion curve acts as the observation operator converting modelled SWE into SCF estimates. Unlike binary indicators of snow presence, the continuous SCF observations can be assimilated with an EnKF, except for snow-free or full cover conditions. We addressed these conditions by supplementing the EnKF with rule-based updates. Figure 1 shows that assimilation of coarse-scale AMSR-E SWE and fine-scale MODIS SCF observations both result in realistic spatial SWE patterns.

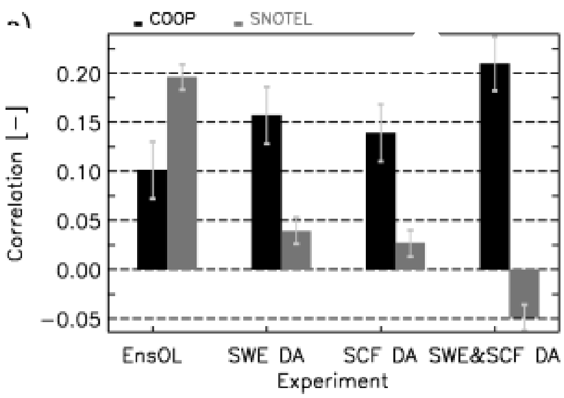

Figure 2: Time series correlation withCOOP (black bars) and SNOTEL (gray bars) in situ observations for model forecasts (EnsOL) and assimilation estimates, computed over 8 winters (October–June 2002–2010) and averaged over the available sites. Also showns are 95% confidence intervals.

AMSR-E retrievals and the upscaled model SWE simulations show large climatological differences. In addition, the comparison of 1 km model simulations against point scale observations suffers from bias due to a different spatial support. To address these biases, experiments with scaled satellite data are also performed. The latter experiments show that the water balance is better preserved with anomaly assimilation than when unscaled (`raw’) observations are assimilated.

The validation of the assimilation results at individual sites over the course of 10 years shows benefit for assimilation in shallow snowpacks, but not in deep snowpacks. Figure 2 shows that at COOP sites (with typically shallow snowpacks), AMSR-E SWE and MODIS SCF data assimilation are beneficial separately, and joint SWE and SCF assimilation yields significantly improved root-mean-square error and correlation values for scaled and unscaled data assimilation. In areas of deep snow where the SNOTEL sites are located, however, AMSR-E retrievals are typically biased low and assimilation without prior scaling leads to degraded SWE estimates (Figure 2). Anomaly SWE assimilation could not improve the interannual SWE variations in the assimilation results because the AMSR-E retrievals lack realistic interannual variability in deep snowpacks. SCF assimilation has only a marginal impact at the SNOTEL locations because these sites experience extended periods of near-complete snow cover. Across all sites, SCF assimilation improves the timing of the onset of the snow season but without a net improvement of SWE amounts.

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