Satellite-scale snow water equivalent assimilation into a high-resolution land surface model

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Overview: Snow is an important component of the land system because of its spatially and temporally discontinuous presence, and its strong impact on the land surface water and energy balance, weather and climate. Land surface models often poorly represent complex snow processes. Enhanced estimates could be expected from assimilation of satellite observations of the snowpacks. Satellite observations of the amount of water stored in the snowpack (or snow water equivalent; SWE) can be obtained from passive microwave sensors, but they are only available at relatively coarse resolutions. In a synthetic study, several assimilation and downscaling techniques are explored to update fine-scale snow estimates using coarse-scale SWE retrievals in an ensemble Kalman filter framework.

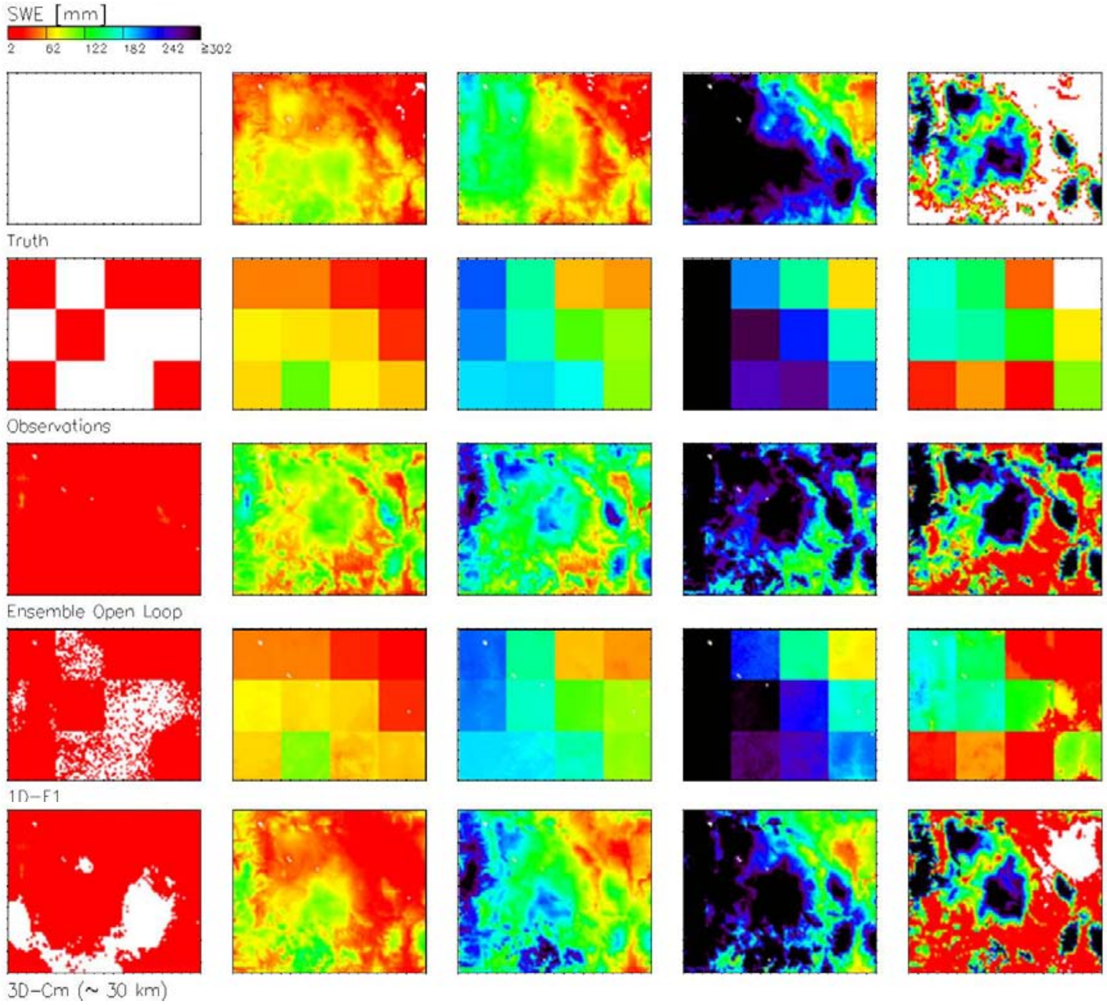

Figure 1: (left to right) Snapshots of SWE fields for 15 Oct 2002, 30 Nov 2002, 15 Jan 2003, 28 Feb 2003, and 15 Apr 2003. (top to bottom) Truth, synthetic observations, ensemble mean open loop forecasts, and analyses obtained with several filter approaches. The spatial correlation length in the forecast perturbations is indicated in parentheses

Results: This study explores a one-dimensional (1D) (or point-wise independent) filter and a variety of three-dimensional (3D) (or spatially distributed) filters to assimilate coarse-scale (~25 km) SWE observations over a small study domain in Northern Colorado, US. The truth is generated at the fine scale (~1 km) by forcing the Noah model with North American Land Data Assimilation System (NLDAS) data. Synthetic observations are generated through aggregation of these fine-scale simulations and addition of observation error. A degraded open loop model integration is simulated by forcing the Noah model with coarse Global Data Assimilation System (GDAS) data and imposing different types of spatially correlated random perturbations.

Figure 1 shows (top row) the "true" reference simulation, (2nd row) the degraded model simulation and (3rd row) the synthetic coarse-scale observations, as well as the analyses for three different assimilation and downscaling techniques.

In technique "1D-F1", the coarse-scale observations are trivially disaggregated to the fine scale before data assimilation and are then assimilated at the fine scale with a 1-dimensional ensemble Kalman filter. As can be seen in Figure 1 (4th row), the 1D-F1 filter pushes the analyses to the coarse observation value, which improves the spatial mean SWE estimation but removes most of the sub-pixel spatial variability. Furthermore, significant fine-scale observation bias is introduced.

The best approach is to assimilate the coarse-scale observations directly with a 3D filter and a properly defined observation operator and forecast error correlation structure. For all 3D filters using the coarse observations it is found that the analyses are best when the spatial forecast error correlation length is equal to or larger than 20–30 km, which corresponds to the dimension of the coarse observation pixels and also to the approximate correlation length of the precipitation error field. The results degrade significantly for shorter correlation lengths. When each fine-scale grid point is updated using 3D assimilation of a single overlying coarse observation, the spatial mean SWE field can be improved over that of the observations or open loop simulations alone, and the spatial sub-pixel variability can be enhanced slightly (not shown). With the additional inclusion of surrounding coarse-scale observations (3D assimilation, using multiple coarse scale observations, "3D-Cm") there is a significant improvement in estimating the sub-pixel variability (bottom row in Figure 1). Furthermore, artificial boundaries in the analysis field, caused by the boundaries in the coarse observations, are completely removed.

It is shown that coarse-scale, synthetic satellite estimates of SWE can improve both the fine-scale SWE spatial mean and variability estimation over the open loop simulations, and the 3D assimilation analyses are always better than either the model simulations or observations alone.

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