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A comparative investigation of sequential ensemble-based schemes for multivariate assimilation of snow data at different Alpine sites

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Because snow melt-water supplies a significant component of the annual water budget in many regions, the knowledge of snowpack dynamics is of critical importance to several real-time applications such as agricultural production, water resource management, flood prevention, and hydropower generation. With the aim of improving the hydrological predictions in snow-dominated areas, an increasing interest focuses on the combined used of different sources of information by assimilating observed data (i.e. ground-based measurements and remotely sensed observations) within models. Several data assimilation (DA) techniques with different degrees of complexity have been developed and are currently used for operational purposes. Generally, the research community agrees on the superior performance of the multivariate DA with respect to the univariate one.
This study intends to assess the feasibility of a multivariate DA scheme for snow modelling through two of the most widely used sequential ensemble-based DA techniques, namely the Ensemble Kalman Filter (EnKF) and the Particle Filter (PF). A dual purpose firstly aims at identifying and overcoming the most constraining limitations in implementing multivariate DA schemes within a snow module. Secondly, the goal is to analyze the main differences in the effectiveness of the two selected DA techniques in consistently updating the snowpack states, in order to assess their suitability to be operationally effective for real-time hydrological applications.
The modelling system consists of a newly developed multilayer energy- and mass-balance snowpack model coupled with a multivariate DA scheme. The system is tested at three Alpine sites: Torgnon (Italy), Col de Porte (France) and Weissfluhjoch (Switzerland). Both DA configurations are analyzed in order to assess their performances in assimilating in-situ snow measurements and the resulting impact on the simulations of the snowpack model, under changing local conditions.
A comparative analysis between the selected DA techniques has allowed to prove that both methodologies are well suited to being used for a multivariate DA application, since they allow to take into account different sources of uncertainty. With respect to the PF scheme, the Kalman filtering generally ensures a larger reduction of the error affecting the model predictions at the assimilation steps, but the sizeable EnKF-based updates do not guarantee the internal physical consistency of the ensemble analysis states. The differences in the filters updating result in larger discontinuities affecting the trend of the EnKF-based analysis simulations, while the smoother trend ensured by the PF technique is assumed to be more properly compliant with the snowpack system physics.
Between two following assimilation time steps, the model predictions generally turn out to be properly conditioned by the filters updating effect, whose temporal persistence mainly depends on the dynamics of the physical evolution of each state variable, than on the scale the filters updates themselves.