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Snow multivariable data assimilation for hydrological predictions in mountain areas

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The seasonal presence of snow on alpine catchments strongly impacts both surface energy balance and water resource. Thus, the knowledge of the snowpack dynamics is of critical importance for several applications, such as water resource management, floods prediction and hydroelectric power production.
Several independent data sources provide information about snowpack state: ground-based measurements, satellite data and physical models. Although all these data types are reliable, each of them is affected by specific flaws and errors (respectively dependency on local conditions, sensor biases and limitations, initialization and poor quality forcing data). Moreover, there are physical factors that make an exhaustive reconstruction of snow dynamics complicated: snow intermittence in space and time, stratification and slow phenomena like metamorphism processes, uncertainty in snowfall evaluation, wind transportation, etc.
Data Assimilation (DA) techniques provide an objective methodology to combine observational and modeled information to obtain the most likely estimate of snowpack state. Indeed, by combining all the available sources of information, the implementation of DA schemes can quantify and reduce the uncertainties of the estimations.
This study presents SMASH (Snow Multidata Assimilation System for Hydrology), a multi-layer snow dynamic model, strengthened by a robust multivariable data assimilation algorithm. The model is physically based on mass and energy balances and can be used to reproduce the main physical processes occurring within the snowpack: accumulation, density dynamics, melting, sublimation, radiative balance, heat and mass exchanges. The model is driven by observed forcing meteorological data (air temperature, wind velocity, relative air humidity, precipitation and incident solar radiation) to provide a complete estimate of snowpack state. The implementation of an Ensemble Kalman Filter (EnKF) scheme enables to assimilate simultaneously ground-based and remotely sensed data of different snow-related variables (snow albedo and surface temperature, Snow Water Equivalent from passive microwave sensors and Snow Cover Area).
SMASH performance was evaluated in the period June 2012 – December 2013 at the meteorological station of Torgnon (Tellinod, 2 160 msl), located in Aosta Valley, a mountain region in northwestern Italy. The EnKF algorithm was firstly tested by assimilating several ground-based measurements: snow depth, land surface temperature, snow density and albedo. The assimilation of snow observed data revealed an overall considerable enhancement of model predictions with respect to the open loop experiments. A first attempt to integrate also remote sensed information was performed by assimilating the Land Surface Temperature (LST) from METEOSAT Second Generation (MSG), leading to good results. The analysis allowed identifying the snow depth and the snowpack surface temperature as the most impacting variables in the assimilation process. In order to pinpoint an optimal number of ensemble instances, SMASH performances were also quantitatively evaluated by varying the instances amount. Furthermore, the impact of the data assimilation frequency was analyzed by varying the assimilation time step (3h, 6h, 12h, 24h).