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Assimilation of streamflow and soil moisture observations in a distributed physically-based hydrological model

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Data assimilation techniques not only enhance model simulations and predictions, they also give the opportunity to pose a diagnostic on both model and observations used in the assimilation process. The goal of this research is to assimilate streamflow and soil moisture in a distributed physically-based hydrological model, CATHY (CATchment HYdrology). The study site is the des Anglais Watershed, a 690-km2 river basin located in southern Québec, Canada. An ensemble Kalman filter was used to assimilate streamflow observations at the basin outlet and at interior locations, as well as soil moisture at different depths (15, 45, and 90 cm) measured with probes (6 stations) and surface soil moisture estimated from radar remote sensing. The use of a Latin hypercube sampling instead of the Monte Carlo method to generate the ensemble reduced the size of ensemble, and therefore the calculation time. An important issue in data assimilation is the estimation of error covariance matrices. Different post-assimilation diagnostics, based on innovations (observation-minus-background), analysis residuals (observation-minus-analysis) and analysis increments (analysis-minus-background) were used to evaluate assimilation optimality. A calibration approach was performed to determine the standard deviation of model parameters, forcing data and observations that lead to optimal assimilations.

The analysis of innovations showed a lag between the model prediction and the observation during rainfall events. The assimilation of streamflow observations (outlet or interior locations) corrected this discrepancy. The assimilation of outlet streamflow observations improved the Nash-Sutcliffe efficiencies (NSE) at both outlet and interior point locations. The structure of the state vector used in this study allowed the assimilation of outlet streamflow observations to have an impact over streamflow simulations at interior point locations. Indeed, the state vector contains the outlet streamflow (Qout) and the incoming streamflow (Qin), since both these informations are used by the Muskingum-Cunge surface routing equation in CATHY. However, assimilation of streamflow observations increased systematically the soil moisture values simulated at 15 and 45 cm. The combined assimilation of outlet streamflow and soil moisture improved the NSE of streamflow without degrading the simulation of soil moisture. Moreover, the assimilation of streamflow and soil moisture observations from one station (at 45 cm depth) appeared to have a similar impact on soil moisture simulations compared to a combined assimilation of streamflow and soil moisture observations from five stations. Finally, it was found that the frequency of the assimilation of soil moisture observations has a greater impact on the results than the spatial coverage of the assimilation: assimilation of daily soil moisture measured with probes at six stations gives better results than the assimilation of surface soil moisture estimated from radar remote sensing 8 times over the course of a summer season.