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Added-value of satellite soil moisture assimilation in hydrological modelling: an evaluation through a large experiment over Europe

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The increasing availability of remotely sensed soil moisture (SM) observations has brought great interest in their use in data assimilation (DA) frameworks in order to improve streamflow simulations. However, the added-value of assimilating satellite SM into rainfall-runoff models is still difficult to be quantified, and much more research is needed to fully understand benefits and limitations.

Here, an extensive evaluation of remotely sensed SM assimilation on hydrological model performances was carried out, involving 775 catchments across Europe. Satellite observations for over a decade from the three ESA CCI SM products (ACTIVE, PASSIVE and COMBINED) were assimilated in a lumped rainfall-runoff model which includes a thin surface layer in its soil schematization, by using the Ensemble Kalman Filter (EnKF). Observations were mapped into the space of modelled surface layer SM through a monthly CDF-matching prior to DA, while the observation error variance was calibrated in every catchment in order to maximize the assimilation efficiency.

The implemented DA procedure, aimed at reducing only random errors in SM variables, generally resulted in limited runoff improvements, although with some variability within the study domain. Factors emerging as relevant for the assessment of assimilation impact were: i) the open-loop (OL) model performance; ii) the remotely sensed SM accuracy for hydrological purposes; iii) the sensitivity of the catchment response to soil moisture dynamics; and also iv) issues in DA implementation (e.g., violations in theoretical assumptions).

The open-loop model results contributed significantly to explain differences in assimilation performances observed within the study area as well as at the seasonal scale; overall, the high OL efficiency is the main cause of the slight improvements here observed after DA. The integration of satellite SM information, showing greater skills in correspondence of poorer streamflow simulations, confirmed a potential in reducing the effects of rainfall inaccuracies.

The variability in satellite SM accuracy for hydrological purposes was also found to be relevant in DA assessment. The ACTIVE product assimilation generally provided the best streamflow results

within the study catchments, followed by COMBINED and PASSIVE ones, while factors affecting the SM retrieval such as vegetation density and topographic complexity were not found to have a decisive effect on DA results.

Low assimilation performances were obtained when runoff was dominated by snow dynamics (e.g., in the northern areas of the study domain, or in winter season at medium latitudes), due to the SM conditions having a negligible effect on the hydrological response.

Finally, in basins where SM was persistently near the saturation value, deteriorations in hydrological simulations were observed, mainly attributable to violation of error normality hypothesis in EnKF due to the bounded nature of soil moisture.

In conclusion, the added-value of assimilating remotely sensed SM into rainfall-runoff models was confirmed to be linked to multiple factors: understanding their contribution and interactions deserves further research and is fundamental to take full advantage of the potential of satellite SM retrievals, in parallel with their progress in terms of accuracy and resolutions.