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Assimilating satellite soil moisture into rainfall-runoff modelling: towards a systematic study

Christian Massari, Angelica Tarpanelli, Luca Brocca, and Tommaso Moramarco
National Research Council CNR, Research Institute for Geo-Hydrological Protection, Perugia, Italy
(christian.massari@irpi.cnr.it)

Soil moisture is the main factor for the repartition of the mass and energy fluxes between the land surface and the atmosphere thus playing a fundamental role in the hydrological cycle. Indeed, soil moisture represents the initial condition of rainfall-runoff modelling that determines the flood response of a catchment. Different initial soil moisture conditions can discriminate between catastrophic and minor effects of a given rainfall event. Therefore, improving the estimation of initial soil moisture conditions will reduce uncertainties in early warning flood forecasting models addressing the mitigation of flood hazard.
In recent years, satellite soil moisture products have become available with fine spatial-temporal resolution and a good accuracy. Therefore, a number of studies have been published in which the impact of the assimilation of satellite soil moisture data into rainfall-runoff modelling is investigated. Unfortunately, data assimilation involves a series of assumptions and choices that significantly affect the final result. Given a satellite soil moisture observation, a rainfall-runoff model and a data assimilation technique, an improvement or a deterioration of discharge predictions can be obtained depending on the choices made in the data assimilation procedure. Consequently, large discrepancies have been obtained in the studies published so far likely due to the differences in the implementation of the data assimilation technique.
On this basis, a comprehensive and robust procedure for the assimilation of satellite soil moisture data into rainfall-runoff modelling is developed here and applied to six subcatchment of the Upper Tiber River Basin for which high-quality hydrometeorological hourly observations are available in the period 1989-2013. The satellite soil moisture product used in this study is obtained from the Advanced SCATterometer (ASCAT) onboard Metop-A satellite and it is available since 2007. The MISDc ("Modello Idrologico SemiDistribuito in continuo") continuous hydrological model is used for flood simulation. The Ensemble Kalman Filter (EnKF) is employed as data assimilation technique for its flexibility and good performance in a number of previous applications.
Different components are involved in the developed data assimilation procedure. For the correction of the bias between satellite and modelled soil moisture data three different techniques are considered: mean-variance matching, Cumulative Density Function (CDF) matching and least square linear regression. For properly generating the ensembles of model states, required in the application of EnKF technique, an exhaustive search of the model error parameterization and structure is carried out, differentiated for each study catchments. A number of scores and statistics are employed for the evaluation the reliability of the ensemble. Similarly, different configurations for the observation error are investigated.
Results show that for four out six catchments the assimilation of the ASCAT soil moisture product improves discharge simulation in the validation period 2010-2013, mainly during flood events. The two catchments in which the assimilation does not improve the results are located in the mountainous part of the region where both MISDc and satellite data perform worse. The analysis on the data assimilation choices highlights that the selection of the observation error seems to have the largest influence on discharge simulation. Finally, the bias correction approaches have a lower effect and the selection of linear techniques is preferable. The assessment of all the components involved in the data assimilation procedure provides a clear understanding of results and it is advised to follow a similar procedure in this kind of studies.