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Comparing Global Hydrological Models and Combining them with GRACE Data by Dynamic Bayesian Averaging (DBA)

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Historically, hydrological models have been developed to represent land-atmosphere interactions by simulating water storage and water fluxes. These models, however, have their own unique characteristics (strength and weakness) in capturing different aspects of the water cycle, and their results are typically compared to or calibrated against in situ observations such as river runoff measurements. As a result, there may be gross inaccuracies in the (a priori) estimation of water storage states produced by these models. These facts motivate us to develop new combination techniques to evaluate and merge multiple hydrological models with available satellite remote sensing data to generate a more accurate picture of global water storage. Here, the main hypothesis is that merging satellite data with multi-model outputs likely provides more skilful hydrological estimations compared to a single model or data set.

In this study, we present a Dynamic Bayesian Averaging (DBA) approach to compare and merge multi-model water storage simulations with monthly Terrestrial Water Storage (TWS, a vertical summation of surface and sub-surface water storage) estimates from the Gravity Recovery And Climate Experiment (GRACE) satellite mission. DBA combines the benefits of the Kalman Filter (KF) and Bayesian Model Averaging (BMA) techniques and has the capability to deal with various observations and models with different error structures. Based on Bayes theory, the proposed DBA provides time-variable weights for the hydrological models to compute an average of their outputs and to achieve the best fit to GRACE TWS estimates.

Numerically, the DBA method is evaluated by integrating the output of six hydrological and land surface models (PCR-GLOBWB, SURFEX-TRIP, LISFLOOD, HBV-SIMREG, W3RA, and ORCHIDEE) and monthly GRACE TWS estimations (2003-2012) within the world's 33 largest river basins, while considering the inherent uncertainties of all inputs. Our results indicate that DBA correctly separates GRACE TWS estimates into surface water, soil moisture and groundwater compartments. Long-term trends are mostly introduced to the groundwater compartment, which reflect the anthropogenic effects that contain in GRACE data and often do not present in model simulations. We also find that temporal correlations between the DBA-derived individual water storage estimations (surface water, soil moisture, and groundwater) and the El Niño Southern Oscillation (ENSO) index are considerably increased compared to those derived between individual model simulations and ENSO. For example, the correlation coefficient of groundwater storage and ENSO in the Murray River Basin changed from -0.2 to 0.6. For the Nile River Basin, the coefficient changed from 0.1 to 0.4 for soil moisture, and from 0.3 to 0.7 for the surface water compartment. Based on these results, we have gained confidence in this method for improving the characterization of water storage over broad regions of the globe.