EGU2020-19070
https://doi.org/10.5194/egusphere-egu2020-19070
EGU General Assembly 2020

Exploring meso-scale soil water and groundwater storage changes within the USA through a Bayesian combination of GRACE data with monthly 12.5 km model simulations

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Climatic changes in precipitation intensity across the United States (USA) may also affect the frequency and magnitude of drought and flooding events, with potentially serious consequences for water supply across this country. Reliable estimation of water storage changes in the soil root zone and groundwater aquifers is important for predicting future water availability, drought and flood monitoring and weather prediction. In this study, we assimilate Terrestrial Water Storage (TWS) derived from Gravity Recovery and Climate Experiment (GRACE) satellite observations into a water balance model with 12.5-km spatial resolution. Our goal is to explore meso-scale surface and deep-level soil water storage, as well as groundwater changes within the USA covering the period 2003-2017. A new Bayesian approach is formulated and implemented in this study, which provides a dynamic solution for a state-space equation between hydrological model outputs and TWS observations, while considering their error structures. The unknown state parameters and temporal dependency between them are estimated through a combination of forward/backward Kalman Filtering and Markov Chain Monto Carlo (MCMC) methods.

The outputs of this methodological approach are evaluated using in situ data from historical USGS groundwater data (over 6600 wells) and the ESA CCI surface soil moisture data. The results indicate that our GRACE data assimilation generally improves the simulation of groundwater and soil moisture across the USA. For example, the long-term linear trend fitted to the Bayesian-derived groundwater and soil water storage are in a same direction as those of in situ data in 63% and 58% of regions studied across the USA, respectively. However, this vale is estimated less than 51% for both water storage estimates derived from the original water balance model, which suggesting that the data assimilation modulates the hydrological models to perform more realistically. The biggest improvements are observed in the southeast USA with considerably large inter-annual variability in precipitation, where modelled groundwater apparently responded too strongly to the changes in atmospheric forcing. The Bayesian data assimilation method also improves the temporal correlation coefficients between the in situ USGS and ESA CCI data and model outputs after merging with GRACE TWS estimates. For instance, the correlation coefficient between groundwater storage and USGS observation increased from -0.52 to 0.48 and from -0.28 to 0.25 in southeast and southwest of USA, respectively. Finally, we will explore changes in Bayesian-derived groundwater and soil water storage within the Florida, California and South of Mississippi regions and interpret their relations with climate-induced factors such as precipitation and ENSO index.

Keywords: USA; Data Assimilation; Bayesian Method; Kalman Filtering; MCMC; GRACE; W3RA; groundwater storage; soil water storage; USGS; ESA CCI.