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Improving estimates of water resources in a semi-arid region by assimilating GRACE data into the PCR-GLOBWB hydrological model

Natthachet Tangdamrongsub (1), Susan Steele-Dunne (2), Brian Gunter (1,3), Pavel Ditmar (1), Edwin Sutanudjaja (4), Yu Sun (1), Ting Xia (5), Zhongjing Wang (5,6)

(1) Department of Geoscience and Remote Sensing, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands, (2) Department of Water Resources, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands, (3) School of Aerospace Engineering, Georgia Institute of Technology, Atlanta, The United States of America, (4) Department of Physical Geography, Faculty of Geosciences, Utrecht University, Utrecht, The Netherlands, (5) Department of Hydraulic Engineering, Tsinghua University, Beijing, China, (6) State Key Lab of Hydroscience and Engineering, Tsinghua University, Beijing, China

An accurate estimate of water resources is critical for proper management of both agriculture and the local ecology, particularly in semi-arid regions where water is scarce. Imperfections in model physics, uncertainties in model land parameters and meteorological data, and the human impact on land changes often limit the accuracy of hydrological models in estimating water storages. To address this problem, this study investigated the assimilation of Terrestrial Water Storage (TWS) estimates derived from the Gravity Recovery And Climate Experiment (GRACE) data using an Ensemble Kalman Filter (EnKF) approach. The region considered was the Hexi Corridor of Northern China. The hydrological model used for the analysis was PCR-GLOBWB, driven by satellite-based forcing data from April 2002 to December 2010. The performance of the GRACE Data Assimilation (DA) scheme was evaluated in terms of its impact on the TWS as well as on the individual hydrological storage estimates. The capability of GRACE DA to adjust the storage level was apparent not only in the TWS but also in the groundwater component, which had annual amplitude, phase, and long-term trend estimates closer to the GRACE observations. This study also assessed the impact of considering correlated errors in GRACE-based estimates. These were derived based on the error propagation approach using the full error variance-covariance matrices provided as a part of the GRACE data product. The assessment was carried out by comparing the EnKF results after excluding (EnKF 1D) and including (EnKF 3D) error correlations with the in situ groundwater data from 5 well sites, and the in situ streamflow data from two river gauges. Both EnKF 1D and 3D improved groundwater and streamflow estimates compared to the results from the PCR-GLOBWB alone (Ensemble Open Loop, EnOL). Although EnKF 3D was inferior to 1D at some groundwater measurement locations, on average, it showed equal or greater improvement in all metrics. For example, the improvement in the correlation coefficient (average from 5 locations) was from 0.06 to 0.63 (1D) and to 0.70 (3D). The RMS difference reduced from 2.06 to 1.55 cm (1D) and 1.19 cm (3D). A modest improvement in the streamflow estimates was similar in 1D and 3D cases. In addition, results from the 9-year long GRACE DA study were used to assess the status of water resources over the Hexi Corridor. Areally-averaged values revealed that TWS, soil moisture, and groundwater storages over the region decreased with an average rate of approximately 0.3, 0.2, 0.1 cm/yr, respectively during the study period. A substantial decline in TWS (approximately –0.5 cm/yr) was seen over the Shiyang River Basin in particular, and the reduction mostly occurred in the groundwater layer. An investigation of the relationship between water resources and agriculture in the region was conducted. It showed that the groundwater consumption required to maintain the growing period in this specific basin was probably the cause of the groundwater depletion.