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Understanding GRACE total water storage estimates with integrated hydrologic modeling across the continental United States

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Modeling the terrestrial water cycle at the global scale has recently been referred to as the "grand challenge to hydrology", which would enhance our understanding of scale- dependent relationships between subsurface and surface regimes, between land and atmosphere, and between human-induced ecohydrologic impacts, including groundwater withdrawals and climate change. Modern advancements in remote sensing have awarded scientists with the ability to measure mesoscale changes in Earth's terrestrial water storage. The Gravity Research and Climate Recovery (GRACE) Program measures fluctuations in Earth's gravity attributable to mass flux, or changes in total water storage (TWS). However, GRACE TWS estimates are not without error and are limited in scale. GRACE uncertainty is still a topic of much discussion, and its products range in lateral resolution from 3° to 0.5°. Further, while we can infer from GRACE products the change in mass storage in a given region from a baseline value, we do not know the total mass available, nor can we distinguish between processes driving mass change such as recharge anomalies, natural variability or human influence (e.g. pumping, irrigation, or diversions). Determining the availability and fluctuations in water resources for governance at the regional or major aquifer scale either involves downscaling coarse remote observations such as GRACE, or interpolating point observations (wells), both of which introduce uncertainty.

Here, we use an integrated hydrologic model, ParFlow, to support and better understand estimates of TWS from GRACE products in the continental United States. The CONUS ParFlow configuration extends over a 6.3 million square kilometer are of the continental United States at 1-km lateral resolution. In previous studies, the CONUS model has been used to analyze continental-scale patterns of water table depth and its mechanistic relationship with topographic indices, recharge and evapotranspiration. This study seeks to use ParFlow to explain sources of groundwater storage loss or gain in major U.S. watersheds that are observed by the GRACE remote sensing products. The CONUS model was run for water years 2009 through 2013 and compared to GRACE GFZ, JPL, and CSR gain-corrected time series. We identify regions in which ParFlow CONUS simulated storage change results fall inside the spread of GRACE leakage and measurement error, adding confidence to both the physically model and remote sensing product. We also use ParFlow to explain partitioning of GRACE TWS into changes in snow water equivalent, soil moisture, groundwater, and surface water. This study illustrates the benefit of extreme-scale hydrologic modeling, in that it may be used to help bridge existing scale gaps between point observations and remote sensing, attribute sources of large scale storage trends, and inform water resource governance at a range of scales.