Assimilation of GRACE terrestrial water storage data into a land surface model: Results for the Mississippi River basin

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Overview: The Gravity Recovery and Climate Experiment (GRACE) satellite mission provides unprecedented observations of variations in terrestrial water storage (TWS), albeit at low spatial (>105 km2) and temporal (monthly) resolutions. Depending on topographic and climatologic conditions, TWS variability may be dominated by ground water, soil moisture, surface water, and/or snow. Zaitchik et al. (2008) assimilated terrestrial water storage (TWS) data from GRACE for the Mississippi River basin into the GMAO Land Data Assimilation System (GMAO-LDAS). The Catchment model that is part of the GMAO-LDAS is well-suited for GRACE assimilation because of its implicit representation of the water table and the fact that groundwater is a dynamic component of TWS.

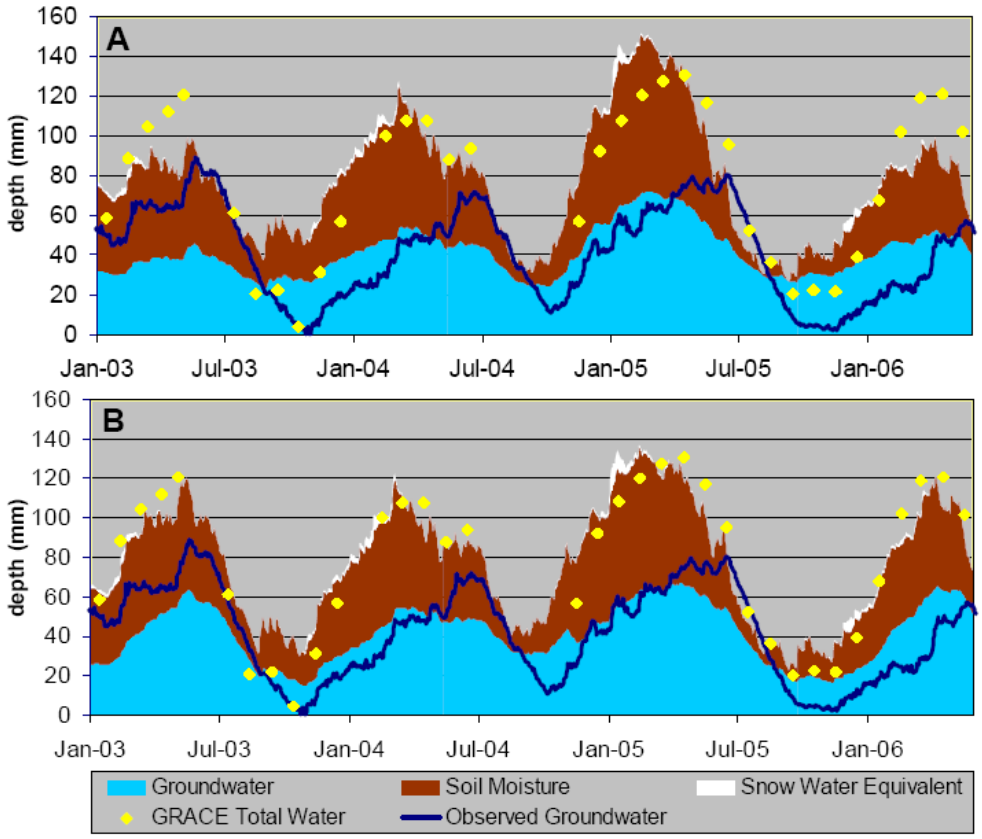

Figure 1: Groundwater, soil moisture, and snow water equivalent for the Mississippi river basin for estimates from (A) the model without assimilation and (B) the GRACE assimilation integration. Also shown are (solid line) area averaged daily in situ groundwater observations and (diamonds) monthly GRACE-derived TWS anomalies. Note that GRACE assimilation improves agreement of the groundwater estimates with in situ data. GRACE and modeled TWS are adjusted to a common mean, as are observed and modeled groundwater.

Results: Because of the temporally integrated nature of the GRACE observations, the EnKF component of the GMAO-LDAS was modified to work effectively as an ensemble smoother. GRACE observations were not scaled for assimilation except that the GRACE-derived TWS anomalies were converted to absolute TWS values by adding the corresponding time-mean TWS from a Catchment model simulation. The ensemble perturbations that were added to the model forcing and prognostic variables were generated with a horizontal correlation scale of 2 degrees, which roughly represents error scales in global-scale precipitation fields (Reichle and Koster 2003). For snow-free catchments, assimilation increments were applied to the catchment deficit variable. For snow-covered catchments, positive increments were applied entirely to snow. Negative increments were applied first to snow and then, if all snow was removed, to the catchment deficit.

The GMAO-LDAS separates the contributions of GRACE observations into individual TWS components and downscales the GRACE observations to scales (~103 km2) typical of global land surface integrations. Assimilation products include catchment-scale groundwater, root zone soil moisture, surface heat fluxes, and runoff. The spatial resolution of the assimilation products is much higher than that of GRACE observations alone, making the results useful for water resources and forecasting applications. Figure 3 shows that the groundwater time series from the GRACE assimilation integration resembles in situ estimates more closely than model estimates alone. Table 1 quantifies the agreement between estimated and observed groundwater for the Mississippi as a whole and for its four sub-basins and demonstrates that GRACE data assimilation significantly improved estimates of the amplitude and phase of the seasonal cycle of groundwater. In all cases, the GRACE assimilation integration exhibited smaller RMS errors than the model integration without assimilation, with RMS error reductions ranging from 7 % to 36 %.

Assimilation of GRACE observations also produced improved estimates of hydrologic variability at the sub-observation scale and a small increase in correlation between runoff estimates and gauged river flow in the majority of test watersheds (not shown). Evaluation of the assimilation results at scales finer than the GRACE data revealed no degradation of model performance due to the assimilation of the coarse GRACE observation. The results demonstrate that – through data assimilation – coarse resolution, vertically integrated TWS anomalies from GRACE can be spatially and temporally disaggregated and attributed to different components of the snow-soil-aquifer column in a physically meaningful way. The results emphasize the potential of GRACE observations to improve the accuracy of hydrologic model output, which will benefit water cycle science and water resources applications.

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