**Title**

Regularizing GRACE mascon solutions using river run-off data

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**Abstract**

Accurate estimates of terrestrial water storage variations (TWSV) are critical for a variety of applications, e.g., model calibration and climate studies. This study aims to find the added value of river run-off data for regularizing GRACE mascon solution, from which TWSV can be estimated. Most subbasins of the Mississippi Basin show an exponential relationship between run-off and TWSV with moderate to good predictive value. The mean value of the explained variance (R^2) for the models is 0.4, when excluding the Lower Mississippi and Middle Missouri subbasins the mean value increases to 0.5. The Lower Mississippi and Middle Missouri subbasins are the only subbasins with no clear correlation between run-off and storage, most likely due to aquifer depletion.  
  
Since ready-to-used GRACE mascon solutions cannot be modified, the mascon method developed at the Geoscience and Remote Sensing Department of the Delft University of Technology is used in this study. This study proposes modifications to tailor this method to the Mississippi Basin and mass anomalies of hydrological origin. After applying standard Tikhonov regularization, the exponential relationship is used to determine the most probable model outcome for each subbasin, adding a new term to the estimator. The resulting GRACE mascon solutions (Tikhonov and run-off regularized solutions) have a root-mean-square deviation (RMSD) of around 3.5 cm when compared to ready-to-use mascon solutions from the Jet Propulsion Laboratory and Goddard Space Flight Center. The run-off regularized solutions show smaller deviation (on average 7 %) than the Tikhonov regularized solutions with respect to an independent validation data set. The largest difference between the Tikhonov and run-off regularized solutions occur in the dryer subbasins (Platte, Middle, and Upper Missouri, and Upper Mississippi subbasin). These areas show a stronger inter-annual trend in TWSV, these trends are captured better by the run-off regularized solutions. Additional research, co-estimating the regularization bias, shows that the run-off regularized solutions induce less bias into the solutions. This study shows that using run-off data when processing GRACE data could be of added value, especially in semi-humid to arid areas, since the TWSV in these areas is more susceptible to inter-annual variations.