A hierarchical Constrained Bayesian (ConBay) approach to jointly estimate water storage and post glacier rebound from GRACE(-FO) and GNSS data

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Gravity Recovery and Climate Experiment (GRACE) and its Follow-On mission (GRACE-FO) provide time-variable Earth's gravity fields that contain signals related to different processes such as non-steric sea level changes, Terrestrial (surface and sub-surface) Water Storage Changes (TWSC), ice sheet melting, and Post Glacial Rebound (PGR). Although the GRACE(-FO) data represent an accurate superposition of these anomalies, separating them into individual storage and surface deformation contributors is desirable for many geodynamic and hydro-climatic applications. Particularly, for hydrological applications, the PGR is often removed as a linear trend, during the post-processing, using the output of Glacial Isostatic Adjustment (GIA) models. As a result, estimating trends in TWSC depends on the accuracy of GIA models, which has considerable uncertainties. In this study, a hierarchical constrained Bayesian (ConBay) approach is formulated to apply GRACE(-FO) fields and the uplift rate measurements from the Global Navigation Satellite System (GNSS) stations to simultaneously estimate the contribution of TWSC and PGR. The proposed approach is formulated based on a hierarchical Markov Chain Monte Carlo optimization algorithm to update available information within a dynamic multivariate state-space model, while accounting for the uncertainties of models and observations. To evaluate the proposed approach, its numerical implementation is demonstrated over the Great Lakes area in North America on grids with 0.5-degree spatial resolution, covering 2003-2017, where the W3RA water balance model and the ICE-5G(VM2) GIA model are used as a priori information of individual water storage changes and PGR rates. Validations are done against independent measurements, i.e., in-situ USGS groundwater level observations, as well as independent GNSS measurements (not used in the optimization procedure). The results indicate that the bias between GIA model output and the in-situ GNSS observation reduced by 72% (from 7.8 to 2.2 mm/yr) and the root-mean-square-of-differences between USGS measurements and model-derived groundwater changes is reduced by 36%, after merging observations with models through ConBay. The ConBay updates, introduced to the long-term trends, as well as the seasonal and inter-annual components, are found to be realistic.

keywords: Bayesian Signal Separation; GRACE(-FO); GNSS; Terrestrial Water Storage Changes; Post
Glacial Rebound;