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# Insights about data assimilation frameworks for integrating GRACE with hydrological models

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Improving the understanding of changes in the water cycle represents a challenging objective that requires merging information from various disciplines. Debates exist on selecting an appropriate assimilation technique to integrate GRACE-derived terrestrial water storage changes (TWSC) into hydrological models in order to downscale and disaggregate GRACE TWSC, overcome model limitations, and improve monitoring and forecast skills. Yet, the effect of the specific data assimilation technique in conjunction with ill-conditioning, colored noise, resolution mismatch between GRACE and model, and other complications is still unclear. Due to its simplicity, ensemble Kalman filters or smoothers (EnKF/S) are often applied. In this study, we show that modification of the filter approach might open new avenues to improve the integration process. Particularly, we discuss an improved calibration and data assimilation (C/DA) framework (Schumacher et al., 2016), which is based on the EnKF and was extended by the square root analysis scheme (SQRA) and the singular evolutive interpolated Kalman (SEIK) filter. In addition, we discuss an off-line data blending approach (Van Dijk et al., 2014) that offers the chance to merge multi-model ensembles with GRACE observations. The investigations include: (i) a theoretical comparison, focusing on similarities and differences of the conceptual formulation of the filter algorithms, (ii) a practical comparison, for which the approaches were applied to an ensemble of runs of the WaterGAP Global Hydrology Model (WGHM), as well as (iii) an impact assessment of the GRACE error structure on C/DA results. First, a synthetic experiment over the Mississippi River Basin (USA) was used to gain insights about the C/DA set-up before applying it to real data. The results indicated promising performances when considering alternative methods, e.g. applying the SEIK algorithm improved the correlation coefficient and root mean square error (RMSE) of TWSC by 0.1 and 6 mm, with respect to the EnKF. We successfully transferred our framework to the Murray-Darling Basin (Australia), one of the largest and driest river basins over the world. Finally, we provide recommendations on an optimal C/DA strategy for real GRACE data integrations.

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