Insights via Space Geodesy: Changes in the Earth's Oblateness (J2) and Length-of-day (LOD) as a New Metric for Hydrological Models

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In this study, we use conservation of the Earth's angular momentum, length-of-day (LOD), and changes in the Earth's oblateness (J_2) to examine the quality of reanalysis hydrology models. In our previous work we demonstrated the closure of the Earth's angular momentum (LOD) budget among its solid Earth (from JPL Kalman Earth Orientation Filter data), atmosphere (from ECMWF reanalyses) and ocean (from the Consortium for Estimating the Circulation and Climate of the Ocean – ECCO) reservoirs at periods from 100 down to 4 days; data from the NCEP reanalysis indicated a negligible contribution from land hydrology on these time scales. Here, we examine in depth the role of land hydrology using the state-of-the-art reanalysis model results from the German Research Centre for Geosciences (GFZ), the Land Dynamics Model (LAD), the Global Land Data Assimilation System (GLDAS), and the Modern Era Retrospective Analysis for Research and Applications (MERRA), and present comparisons of total water column amounts specified by the these reanalyses with global constraints provided by low-order components of the Earth's gravity field as determined from satellite laser ranging (SLR) products provided by the Center for Space Research. While lacking the spatial resolution provided by GRACE retrievals, the Earth's dynamic oblateness J_2, proportional to the C_{20} component of the gravity field, provides a robust constraint on global re-distribution of water mass that is particularly sensitive to meridional displacements and thus to changes in glacier and ice sheet mass balance variations on time scales from sub-seasonal to decadal.

We focus here on the ability of the four reanalysis systems considered to recreate the seasonal cycle in J_2, which has comparable contributions from atmospheric, oceanic, and hydrological mass redistribution. Comparisons among available atmospheric and oceanic products show that their J_2 contribution from mass redistribution are of similar magnitude, when applying the inverted barometer (IB) approximation to the atmospheric terms and the constant-mass assumption to the oceanic analyses. These will be compared with analysis systems that account explicitly for net mass transfers between the land hydrological and oceanic components (in particular GFZ), using a eustatic distribution for net exchange of ocean mass with land hydrology. Similar considerations will be used to assess the separate effect of atmosphere-ocean mass redistribution on J_2, using the GRACE de-aliasing product.

A key focus of the investigation will be the different representations for the changing mass content of glaciers, ice sheets, and seasonal snow cover, since these high-latitude features have a strong signature on J_2, but have often been masked out in comparisons with observed data. By validating the hydrology models on the seasonal cycle, we hope to provide further insight into the time evolution of frozen water reservoirs, both for the period preceding GRACE and to facilitate continued monitoring in a post-GRACE period should that eventuality arise. Since the CSR J_2 series studied here is corrected for solid Earth / ocean tides and pole tides, for example, with no secular trend corresponding to post-glacial rebound removed, the results of these comparisons can be used to gain insight into the interannual J_2 variations found in observations and model results. By ranking the models with respect to their ability to account for the observed seasonal cycle in J_2 following removal of atmosphere-ocean effects, therefore, our study also contributes to the understanding of longer-period variations in the Earth's oblateness and climate.

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