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# Low Degree Gravitational Changes from Earth Rotation, Geophysical Models, and Satellite Gravimetry

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We examine low degree gravitational variations of $C_{21}$, $S_{21}$, and $C_{20}$ from three independent approaches, including using mass-induced excitations of the Earth rotation, surface mass load estimates from atmospheric, oceanic, and hydrological models, and satellite gravity measurements from the Gravity Recovery and Climate Experiment (GRACE) gravity mission. During the first 3 years of GRACE mission (2002 – 2005), these independent estimates show remarkable agreement, especially in $C_{21}$ and $S_{21}$. The less agreement in $C_{20}$ is mainly controlled by un-quantified large uncertainties in the GRACE $C_{20}$ time series (of release 1). With the adoption of improved background geophysical models (e.g., the mean gravity field, ocean tides, solid Earth pole tides, and ocean pole tide), the release 2 GRACE solutions show significant improvement in the estimates of these low degree gravitational changes. Accurately measured Earth rotational changes provide unique and independent constraints to GRACE-observed degree-2 gravitational variations, provided that the excitations introduced by winds and ocean currents can be fairly well modeled by atmospheric and oceanic models.