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Agreement between Earth's rotation and mass displacement as detected by GRACE

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ABSTRACT

The progress in GRACE data processing should improve the estimation of low degree spherical harmonics which are expected to agree better with Earth's rotation observations. The polar motion and length-of-day excitations determined from the spherical harmonics of the GRGS latest release (RL02) are explored and compared to the previous release (RL01). The RL02 gives best fit of the observed annual variations than RL01 and geophysical models do. However, the observed residual signal obtained after removing annual and semiannual oscillations is still better explained by the geophysical models even if RL02 estimates are improved at these frequencies scales. Linear trends are also estimated over study period (2003–2008). The linear trends of χ_1 based on GRACE RL01/02 and EOP are similar but they are very different for χ_2. Further studies with longer time series of GRACE and future gravimetric missions could help better interpret the long term variations and the effects of ice sheet mass loss or post glacial rebound. Concerning LOD variations, GRACE/LAGEOS mass displacement information brings better agreement with EOP observations, compared to the pressure term estimated by models, however the RL02 has not shown significant improvement.

1. Introduction

The primary cause of the excitation of Earth's Orientation Parameters, polar motion and length-of-day, is the mass transport within the geophysical fluids layers (i.e., atmosphere, oceans, and water storage). In the terrestrial frame the inertia moments of the Earth undergo changes due to mass distribution. In addition, relative motion has a significant effect. Thus a time–variable equatorial and axial angular momentum is created, constituted by a mass term and a relative angular momentum (motion term). Because of angular momentum conservation principle, that increment is balanced by motion of the rotation pole with respect to the crust and LOD variations. By estimation of the mass term and relative angular momentum, it is possible to compute the excitation of polar motion and LOD. In the last decades, those quantities have been partially determined with observations and models of the atmosphere and the oceans, which are known to be the main source of angular momentum changes at seasonal and sub-seasonal scales. The assimilation of various meteorological observations into Global Circulation Model allows to estimate the atmospheric angular momentum (AAM) routinely from pressure and wind fields. The determination of the oceanic angular momentum (OAM) is more difficult, because oceanic observations are largely not available. Whereas AAM explains 90% of the LOD variations at seasonal and sub-seasonal scale (Eubanks, 1993) and the combined AAM and OAM series fit well the excitation found in the observed polar motion at seasonal scales (Nastula et al., 1998; Gross et al., 2003), the residual signals show significant discrepancies. That may be due to the defect of OAM model or to the negligence of some other geophysical excitation, linked for example to hydrological processes. The advent of the Gravity Recovery and Climate Experiment (GRACE) mission related to the entire mass distribution of Earth has shed light on the EOP excitations. Variability of the gravity field is now monitored with unprecedented accuracy and spatial resolution since April 2002. The inertia moments are directly related to the spherical harmonics coefficients C_{20}, C_{21} and S_{21} of the geopotential. We can assume that GRACE mission enables the determination of the equatorial and axial part of the variable mass term, independently from any geophysical model. The GRACE mass term has to be compared to the excitation derived from the observed polar motion and LOD. We now have at hand 8 years of observations. Our objective is to understand to which extent mass redistribution observed by GRACE is consistent with Earth's rotation observations.

Such a study was initiated by Chen and Wilson (2003), Chen et al. (2004), and revisited by Nastula et al. (2007) and Chen

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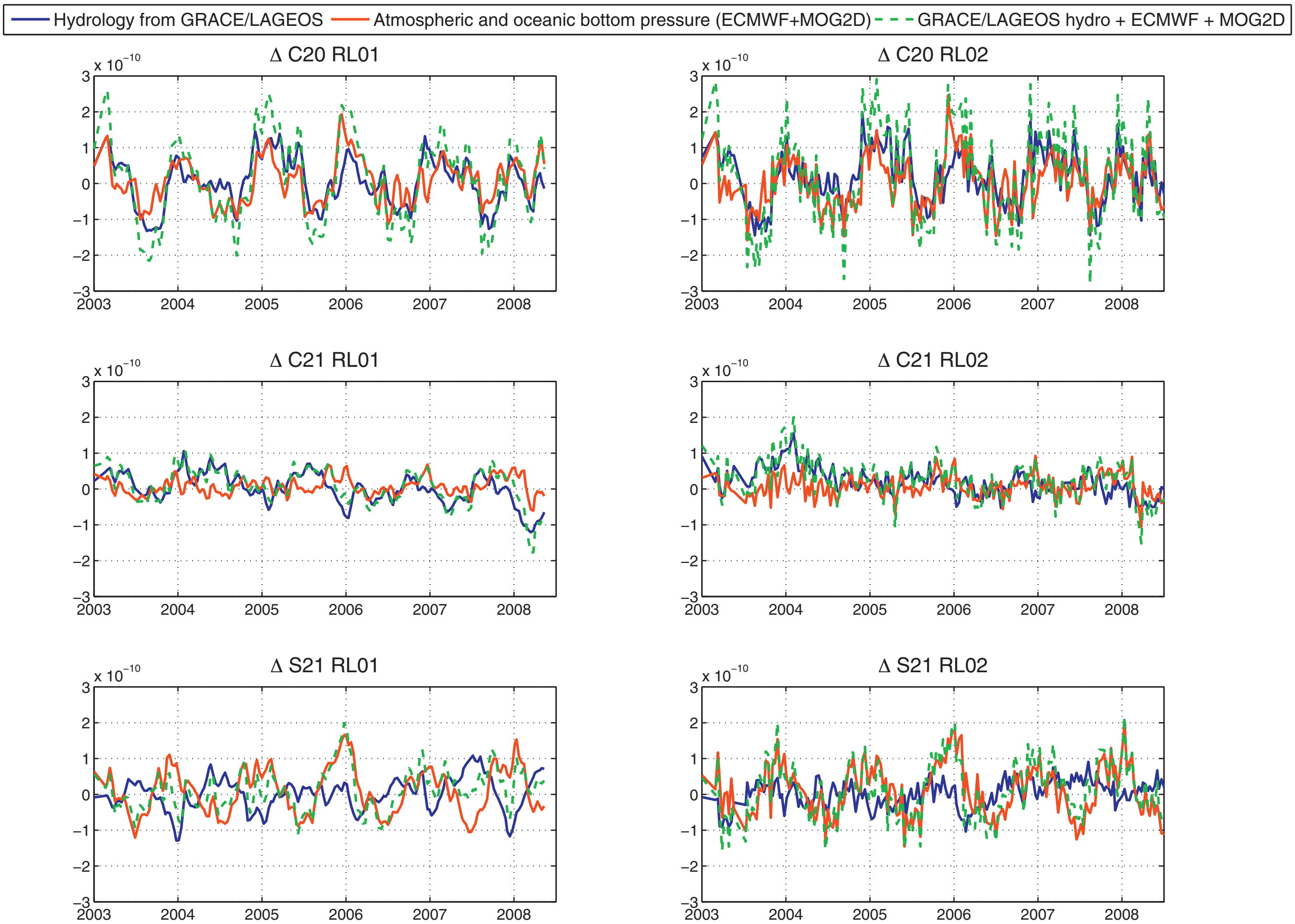

Fig. 1. GRACE/LAGEOS models (essentially hydrological effects) for spherical harmonics C_{20}, C_{21} and S_{21}, non-tidal atmospheric and oceanic models (ECMWF + MOG2D) and their addition (GRACE/LAGEOS + ECMWF + MOG2D). The GRGS release 01 and 02 models are shown.

and Wilson (2008) for previous releases. The improvements in data processing carried out by GRACE project analysis centers (Center of Space Research, CSR; Jet Propulsion Laboratory, JPL; GeoForschungsZentrum, GFZ), show a best estimation of low degrees spherical harmonics (Gross et al., 2008; Brzezinski et al., 2009; Seoane et al., 2009; Jin et al., 2010). In this paper we use the most recently updated solution obtained by the Groupe de Rechercher de Géodésie Spatiale (GRGS) in the latest release RL02 (Bruinsma et al., 2010). For comparison and assessing the improvements in data processing, we considered also the previous release RL01 (Lemoine et al., 2008). Still, the EIGEN-GRGS gravity field models are computed using a different data processing strategy with respect to the other centers solutions and combining GRACE and LAser GEOdynamics Satellites (LAGEOS) data. LAGEOS data provide over 90% of the information on the coefficient C_{20} of the gravity field, whereas GRACE data provide nearly 100% of the information on all other harmonic coefficients.

2. Data

2.1. GRACE-based excitations

Polar motion and LOD excitations are deduced from the relation between normalized spherical harmonic coefficients of the gravity field ($\Delta\bar{C}_{20}$, $\Delta\bar{C}_{21}$, $\Delta\bar{S}_{21}$) and the inertia moments of the Earth in the terrestrial frame. We have used the Chen et al. (2004) formulation for computing excitation functions from GRGS combined GRACE/LAGEOS gravity field solutions:

$$\chi^{\text{mass}} = -\frac{1}{1+k_2'}\sqrt{\frac{5}{3}}\frac{1.098MR^2}{C-A}(\Delta\bar{C}_{21} + i\,\Delta\bar{S}_{21}) \quad (1)$$

$$\Delta LOD^{\text{mass}} = -\frac{1}{1+k_2'}\sqrt{5}\frac{2}{3}\frac{0.754MR^2}{C_m}\Delta\bar{C}_{20} \quad (2)$$

where M and R are respectively the mass and mean radius of the Earth, C and A are the principal inertia moments of the Earth, C_m is the principal inertia moment of the Earth's mantle and $k_2' = -0.310$ is the degree 2 load Love number.

For comparison, we use the first release RL01 gravity field model (30-day models) and the latest release RL02 (10 day-models). The spherical harmonics are corrected from solid Earth tides (McCarthy et al., 2004), oceanic tides using the FES2004 model (Lyard et al., 2006), pole tide (McCarthy et al., 2004), ocean pole tide (Desai, 2002), non-tidal atmospheric and oceanic effects using ECMWF model and MOG2D barotropic model. For C_{21} and S_{21}, LAGEOS is a minor contributor. The relative percentage of participation to the normal equation diagonal is less than 5% (Lemoine, private communication, 2008) and it indicates that nearly 100% of the information is due to GRACE data. However in the case of C_{20}, the 90% of the information comes from LAGEOS.

The non-tidal models have to be added back, in order to compare to polar motion excitation deduced from Earth rotation observations.