Temporal variations of the Earth's gravity field derived from SLR data over a long period of time

F. Deleflie (1)**, J.-M. Lemoine** (2)**, O. Laurain** (1)**, D. Feraudy** (1)

(1) Observatoire de la Côte d'Azur – Geoazur / GRGS, Grasse, France
(2) Centre National d'Etudes Spatiales / GRGS, Toulouse, France

Florent.Deleflie@obs-azur.fr /Fax: +33-4-93405333

Abstract

In addition to the products built by the GRGS Analysis Center and delivered to the ILRS community through the Analysis Working Group, the authors now provide as well, routinely on a weekly basis, time series of the low wavelengths of the Earth's gravity field, namely for degree 2, 3, 4, 5. Over a long period of time, we enlighten temporal variations due to mass redistribution within the Earth's system, as shown by many authors, and especially at the beginning of the decade. We present here our own preliminary results.

Introduction

We use SLR data tracked by the ILRS network (Pearlmann et al., 2002) since more than twenty years to derive long time series of the low wavelengths of the Earth's gravity field. The work is based on a post-fit residuals analysis, performed with the computation of the orbits of geodetic satellites, LAGEOS-1, LAGEOS-2, Starlette in particular. On a weekly basis, normal matrices deduced from each orbital arc are stacked and then inversed to perform time series of gravity field parameters.

1. Post-fit residuals analysis of weekly arcs

1.1. LAGEOS-1

As mentioned in (Métris *et al.*, 1997), a main difficulty to study non gravitational effects acting on LAGEOS-1 orbit is a "lack of firm knowledge of the satellite spin axis evolution. Several important effects, notably the thermal phenomena and the optical anisotropy effect, depend criticaly on the spin axis orientation. A lack of the theoretical understanding of this evolution has posed (and still poses) an important obstacle in the non gravitational force modeling process." This difficulty to model the spin axis orientation has been increased since the middle of the 90's, because the rotation LAGEOS-1 rotation period has been considerably decreased by the action of the eddy current dissipation. In addition to the well-known radiation pressure, and to the discover in 1981 by Smith and Dunn of an unexplained decreasing of the semi-major axis of about 1.1mm/day, (corresponding to a constant along track acceleration of -3.3 10^{-12} m.s^{-2}), different non gravitational effects have been enlightened in the LAGEOS-1 orbit, and produce specific perturbations on the orbital motion (Yarkovsky-Shah thermal effect, asymmetric reflectivity of the satellite surface, asymmetric thermal emissivity of the Earth).

The level of residuals strongly depends, not only on the quality of the orbital model, but also on the number of the adjusted parameters. Hence, some small effects can be "absorbed" through some of the parameters accounting for empirical forces, especially the odd degrees of the Earth's gravity field. Nevertheless, since the periods appearing in the orbital motion and the gravity field are slightly different, we think that we can trust on the temporal variations for the odd parameters (see below).

Weekly orbital arcs of LAGEOS-1 have been built from 1990 to 2006. Figure 1 shows time series of the adjusted empirical parameters, towards the radial, tangential and normal directions, respectively (two sets per week). Some characteristic signals can easily be observed, in particular on the normal direction. Let us note that since there is no physical reason why the radiation pressure coefficient should vary, this coefficient has been constrained to its averaged value (1,02). The averaged rms for weekly arcs is of the order of 1,4cm.

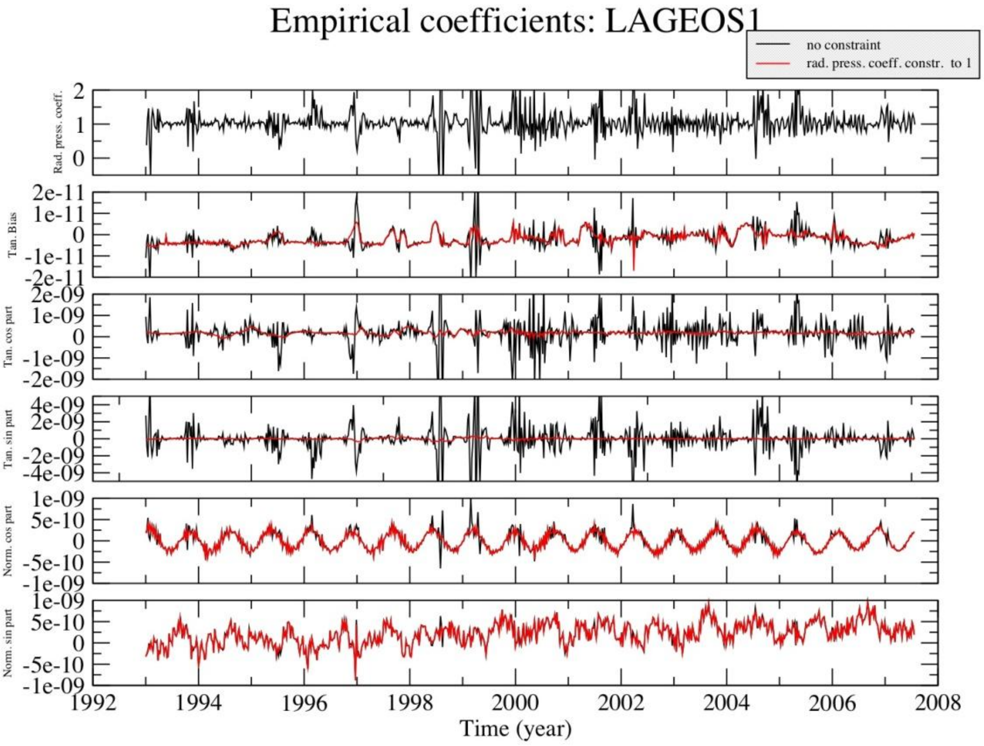

Figure 1. Time series of empirical parameters for LA-1

1.2. LAGEOS-2, and other satellites

The same kind of strategy was used to build weekly arcs of other geodetic satellites. Figure 2 shows the weighted rms for LAGEOS-1, with an orbit modeling very close to the one used for LAGEOS-1, and the number of normal points used for each weekly computation. Some arcs of ETALON-1 have also been used, as well as Starlette (orbital modeling accounting for additional perturbations, such as the atmospheric drag).

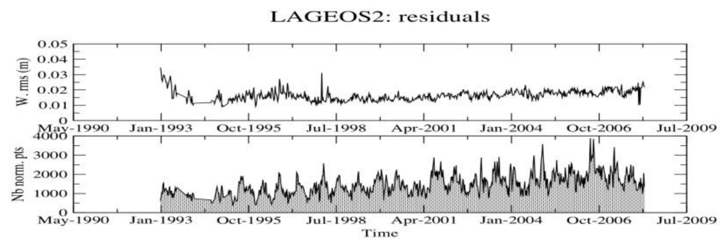

Figure 2. LA-2 weekly post-fit residuals

2. Time series of gravity field parameters

SLR tracking data of geodetic satellites have been used to determine time series of gravitational field harmonics up to degree 5. We show here the results for the degree 2 and the degree 3.

2.1. Degrees 2, 3

Figure 3 shows the time series for the whole degree 2, Figure 5 the time series for the whole degree 3.The black curve is composed by one point every 10 days, and the red one is a running averaging, enlightening seasonal variations. The blue curve shows the temporal variations determined by GRACE measurements (courtesy J.M. Lemoine). The zero line corresponds to the value of the EIGEN-GL04S model.

We compared these temporal variations with the one determined by geophysical models (courtesy O. de Viron), modeling changes in ocean-bottom pressure, and land hydrology. The ocean-bottom pressure series is from “a data assimilating oceanic general circulation model, ECCO (Stammer et al., 2002), constrained by in situ and satellite data including expandable bathyther-mograph data and altimetric measurements of sea surface height. (…) The land hydrology model is the land Dynamics (LaD) model of Milly and Shmakin (2002), which consists of gridded values of the surface mass density of snow, root-zone soil water, an groundwater given at monthly intervals.” (Gross et al., 2009). This comparison is shown Figure 4. The correlation between the two curves gives a poor value. It appears that it seems to exist a good correlation over significant periods of time, but the consistency between values obtained from space data and geophysical models still needs to be improved significantly over the whole period.

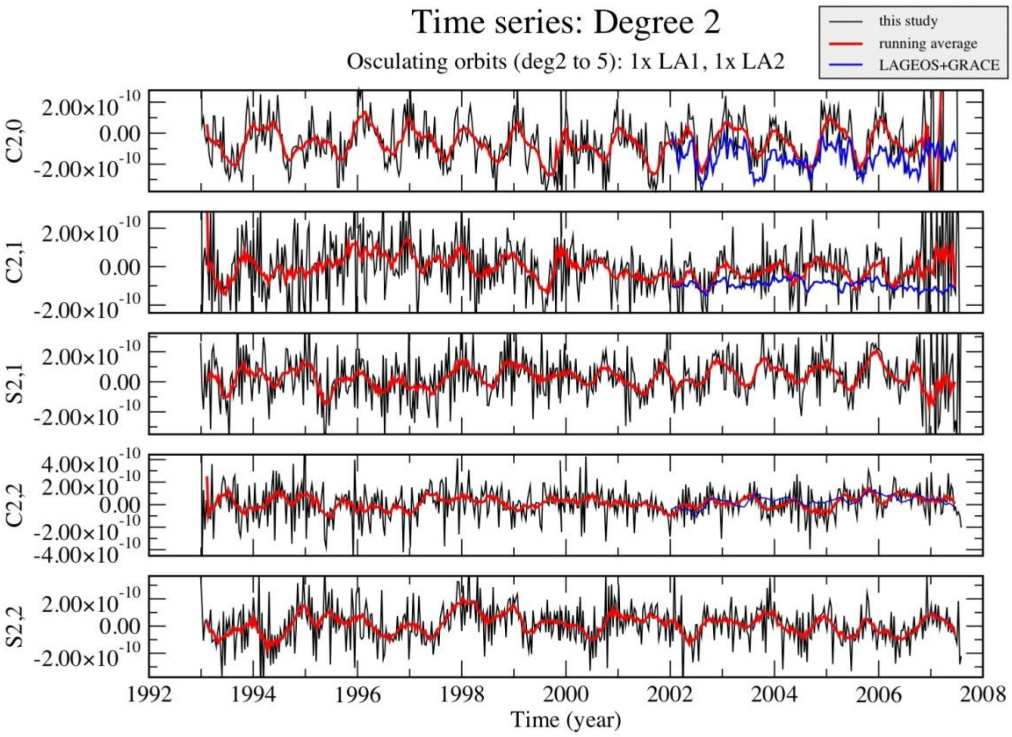

Figure 3. Degree 2 time series (zonal and tesseral coefficients)

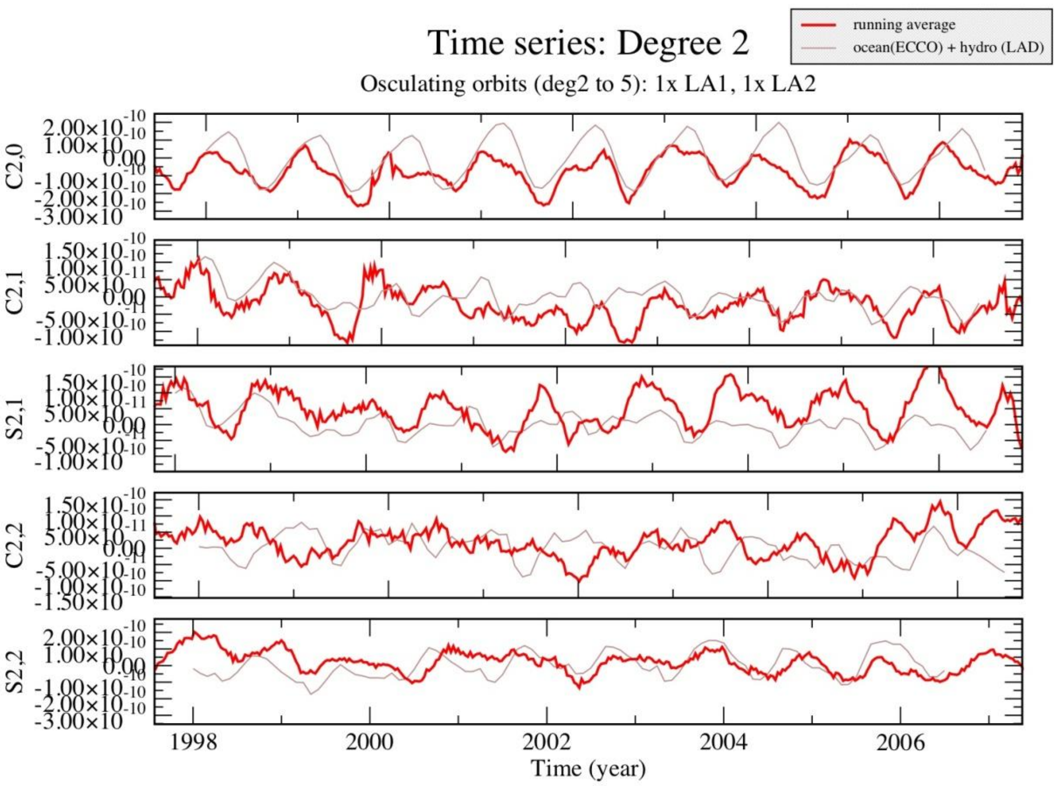

Figure 4. Degree 2: comparison with geophysical models

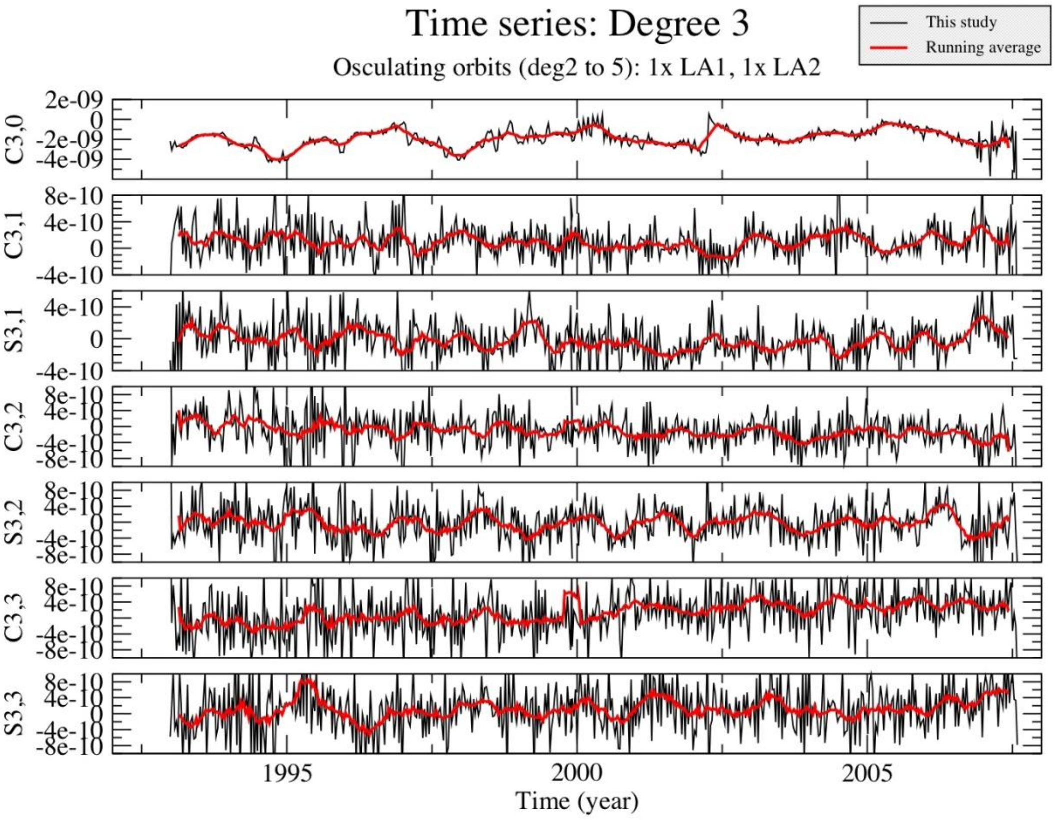

Figure 5. Degree 3 time series (zonal and tesseral coefficients)

2.2. Particular case of the J2 zonal coefficient

Figure 6 is a blow-up of Figure 3 for the C(2,0)=-J2 coefficient. As it is well known SLR data analyses indicate that the earth's dynamic oblateness has undergone significant variations. The dominant signature in the observed variations are mainly (i) a secular decrease linked more or less to the post-glacial rebound, at the level of 4,88 10^{-12} / yr, obtained from a least square fitting to the whole time series (value affected by the 1996-2002 event) (ii) seasonal variations with a mean amplitude of the order of 1.62 10^{-10} (to be compared to the value of (Cheng & Tapley, 2004) of about 3 10^{-10}) and a phase of 187°. There are as well significant interannual variations related to El Nino Southern Oscillation event, especially during the 1996-2002 period.

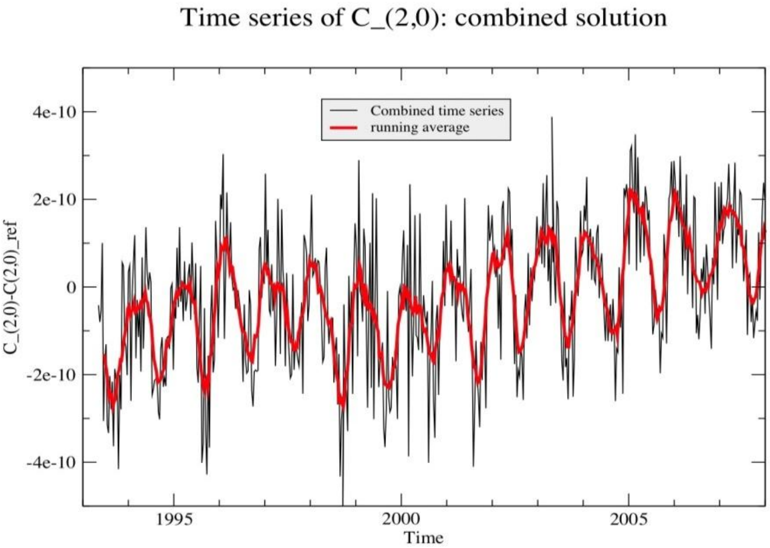

Figure 6. C (2,0) time series

3. Conclusions

Mass variations within the Earth’s dynamic system have a temporal spectrum ranging from hours to decades, and even longer. Many of them are related to both long term and short term climate forcing, and many papers showed that the annual variations of the low wavelengths of the gravity field, and the J2 parameter in particular, can be explained by the existing geophysical models of mass redistribution in the atmosphere, ocean, and continental water. Nevertheless, space data can still contribute to constrain some parameters of these geophysical models, and SLR data, because they are available over a very long period of time, have a strong role to play in that context. Geodetic satellite perturbations need to be carefully analyzed, in order to ensure the best accuracy and decorrelation of the low wavelengths of the gravity field, for the even and odd degrees, in particular for LAGEOS-1 because of the specific non gravitational perturbations. A next step of this work should be to provide an optimal weighting of the contribution of each satellite.

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