A New Model of the Mean Albedo of the Earth: Estimation and Validation from the GRACE Mission and SLR Satellites.

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Abstract

*Part of the energy received on the Earth from the Sun is split into two components, a short wave component which corresponds to the visible emissivity of the Earth's surface (**albedo**), and the long wave part corresponding to the thermic emissivity (**infrared wavelengths**). These two components induce non-gravitational forces on the orbits of artificial satellites, mainly in the radial direction, that we are evaluating in order to derive a new mean model of these effects.*

We analyse three data sets to investigate the order of magnitudes of the orbit perturbations: (i) Stephens tables [1], ECMWF data sets (that are available from CNES, France), and CERES (Clouds and the Earth's Radiant Energy System) data sets (publicly available)[11].

In this poster, first, following an approach close to the one developed by Stephens, we propose a set of monthly grids that are averaged over the period 2000-2015. Second, we analyze what is the data set leading to the lowest residual mean square level in orbital propagation scenarios, by using data from MEO geodetic satellites (Lageos-1, tracked by the ILRS network; and the two GRACE satellites). We give an example of an evaluation carried out over eight years (2004-2011).

1. Albedo modelling

- Estimates of the albedo of the Earth have evolved over time but converge over the past 40 years of satellite record to the present-day value of 0.29 (or equivalently 99.7 $W.m^{-2}$ reflected energy).
- Satellite observations began to be carried out in 1980 by Graeme L. Stephens to give a global albedo model [1]. This model is implemented in GINS, the GRGS orbitography s/w [3][7], as a reference mean model.
- The so-called Stephens model is compared to data sets provided by ECMWF (European Centre for Medium-Range Weather Forecasts) [4], and CERES (Clouds and the Earth's Radiant Energy System)[11].
- We then provide a comparaison in terms of orbits differences, and SLR residuals at the tracking network level.

2. Validity of the new mean models: an analysis

- Stephens et al. have studied in 1980 [1] the annual and seasonal averaged Earth atmosphere radiation budgets derived from the most complete set of satellite observations available in late 1979. **The data was accumulated from samples of 3 to 5 months, between the years 1964 to 1977**.
- The mean value of albedo in Stephens model of **0.30** is slightly different from the current estimate from CERES observations [9]. According to CERES EBAF (Energy Budget Adjusted Fluxes) data, the global, annual mean all-sky reflected flux is 99.7 $W.m^{-2}$ (equivalent to a global albedo of **0.293**) [2].

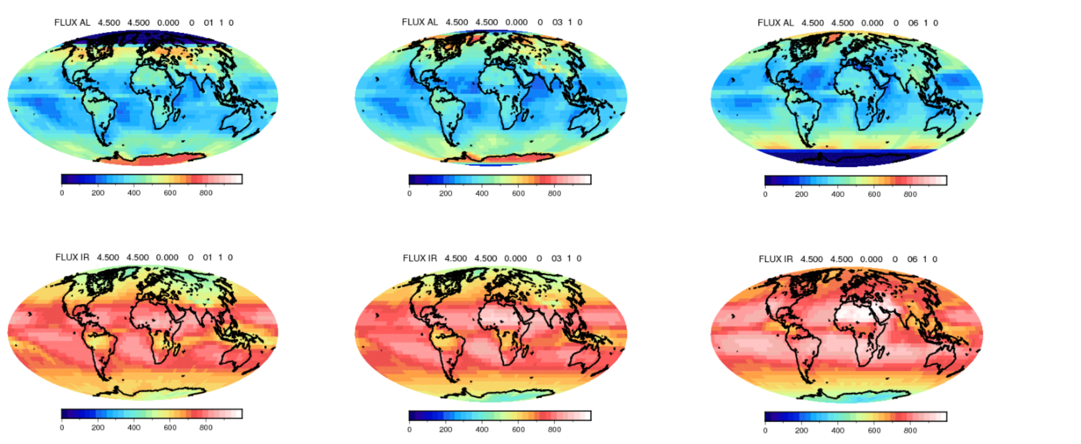

Figure 1: *mean albedo (top) and IR (bottom) for January, March and June (left to right), ECMWF mean model.*

- ECMWF is the European Center for Medium-range Weather Forecast, data from which is measured at the top of atmosphere. It is produced daily, on 4.5° × 4.5° and 9° × 9° grids. Its mean albedo and IR values are **0.369** and **0.713**, respectively [8].

Interpretations (based as well on other curves such as Fig. 1, but not displayed here):

- Shape of differences in the infrared: the three data sets show small differences; the highest compatibility is between EMCWF and CERES;
- The average value of the Earth's albedo according to recent studies is estimated at **0.291** and for the infrared it is around **0.7**, identical to CERES [2]
- Stephens grids also still have values (0.307 for the albedo and 0.699 the IR) close to what is expected over the analyzed period

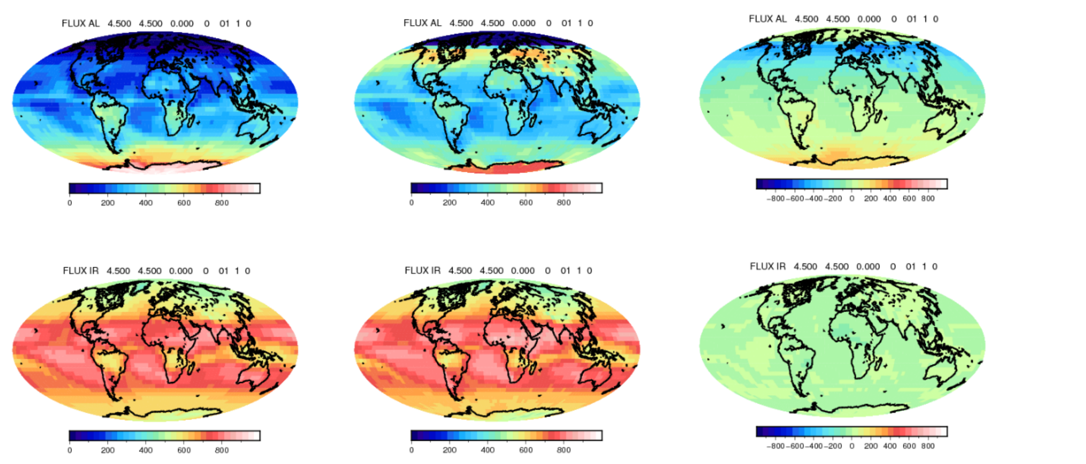

Figure 2: *Albedo (top) and Infrared (bottom) values for CERES (left), ECMWF (middle) and their differences (right) over the Earth for January. Roughly speaking, the differences are structured in four zones, with a location depending upon the seasons.*

3. Perturbation due to albedo on Lageos-1

As an example of the kind of effect induced by the change of the albedo modelling, we computed the orbit of Lageos-1 for a period of 10 days using the various albedo models:

- following the ILRS Analysis Steering Committee (ASC) guidelines;
- testing the impact of the choice of the grids initializing the albedo/IR effects;
- on Fig. 3, it appears that : (i) the difference (bottom) are on a very low (**mm**) level for most of the stations when comparing CERES and Stephens; (ii) for other ones (such as 7825 and 7110), the differences have a significant level (**cm**). These differences can be correlated to the difference between the grids that are significant as well (not shown here).

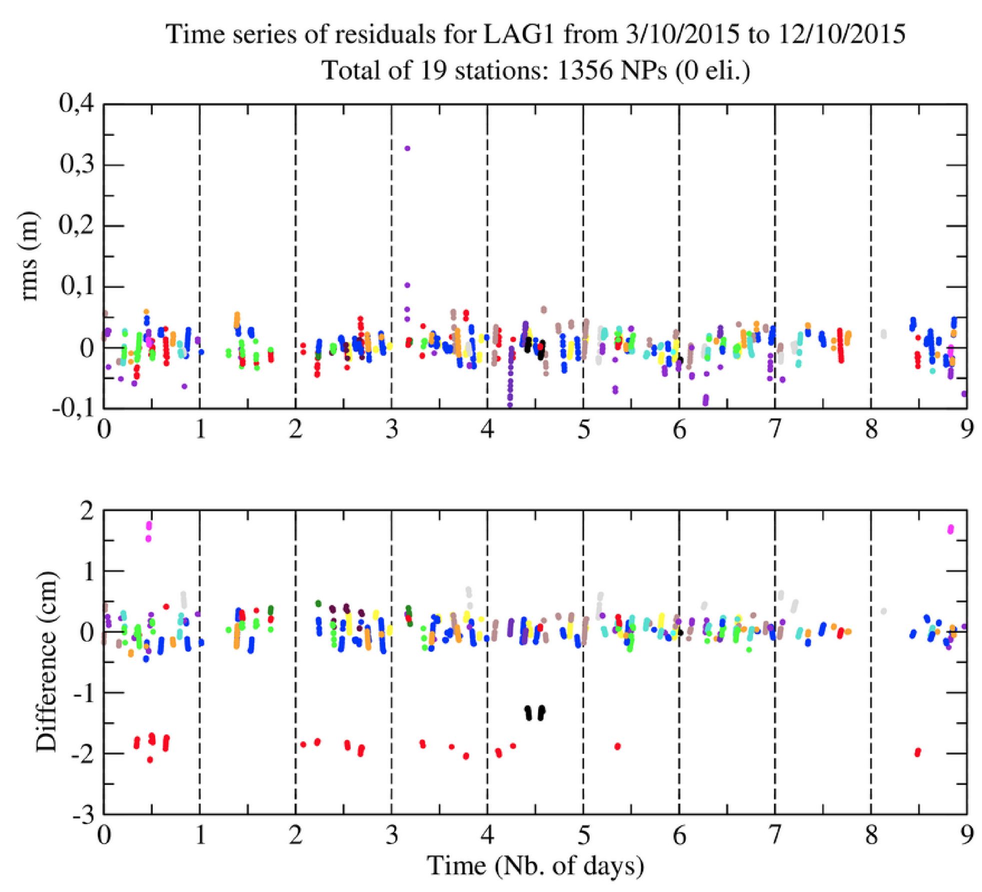

Figure 3: *SLR orbit computation of the Lageos-1 satellite, and values of the residuals, per tracking station of the ILRS [10]. Top: post-fit global rms (cm level, in m); bottom: differences between mean range values using Stephens mean model and CERES grids as the albedo force modelling in the gins s/w.*

4. Perturbation due to albedo on GRACE

The radial correction strategy, originally applied on CHAMP, is adopted to handle the albedo and infrared effects on the GRACE satellites. In the treatments, the degraded measurement along the radial axis (X) is finally replaced by a combination between the STAR measurement along the tangential axis (Y) projected on the radial axis (by application of the "lift / drag" ratio) and the radiation pressure models. This procedure makes it possible to deduce the lift information from the Y axis of the accelerometer:

$$R_X = \frac{C_L}{C_D} * \left(B + F.R_Y^{STAR}\right) - \frac{1}{m}\left(F_Y^{SUN} + F_Y^{albedo} + F_Y^{IR}\right) + \frac{1}{m}\left(F_X^{SUN} + F_X^{albedo} + F_X^{IR}\right) \quad (1)$$

*Ratio (lift / drag) * (STAR / Y acceleration calibrated); Removal / Y of radiation pressure models; Addition / X radiation pressure models*

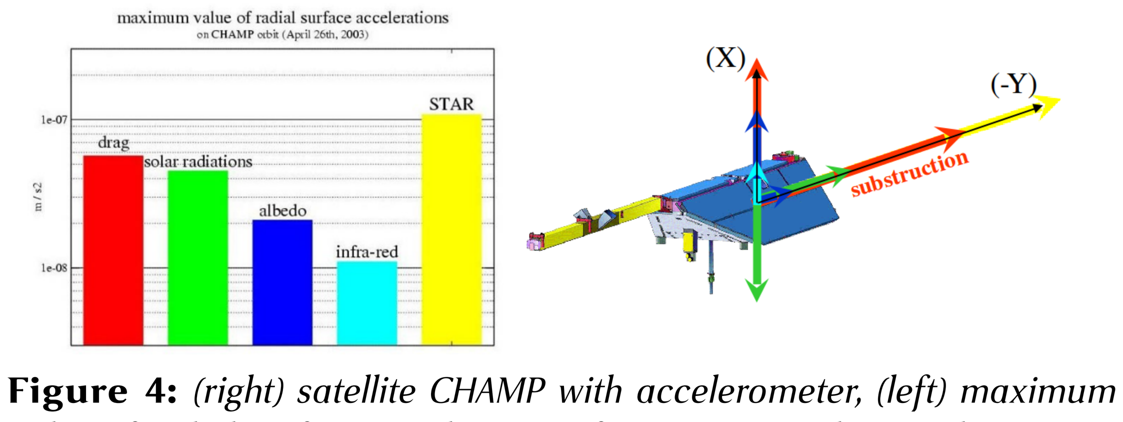

Figure 4: *(right) satellite CHAMP with accelerometer, (left) maximum value of radial surface accelerations from CHAMP orbit (April, 2003) [7].*

- GRACE release 04 (RL04) is one of CNES gravity model products based on accelerometer, GPS and SLR measurements;
- 5-second bulletin files have been updated from RL04 orbits;
- From Fig. 5, it appears that the difference in tangential and normal axis components is negligible comparing with radial component;
- If not that far from the Stephens model, our mean model based on ECMWF grids gives the best fit with accelerometer RL04 values, as seen in Fig. 6.

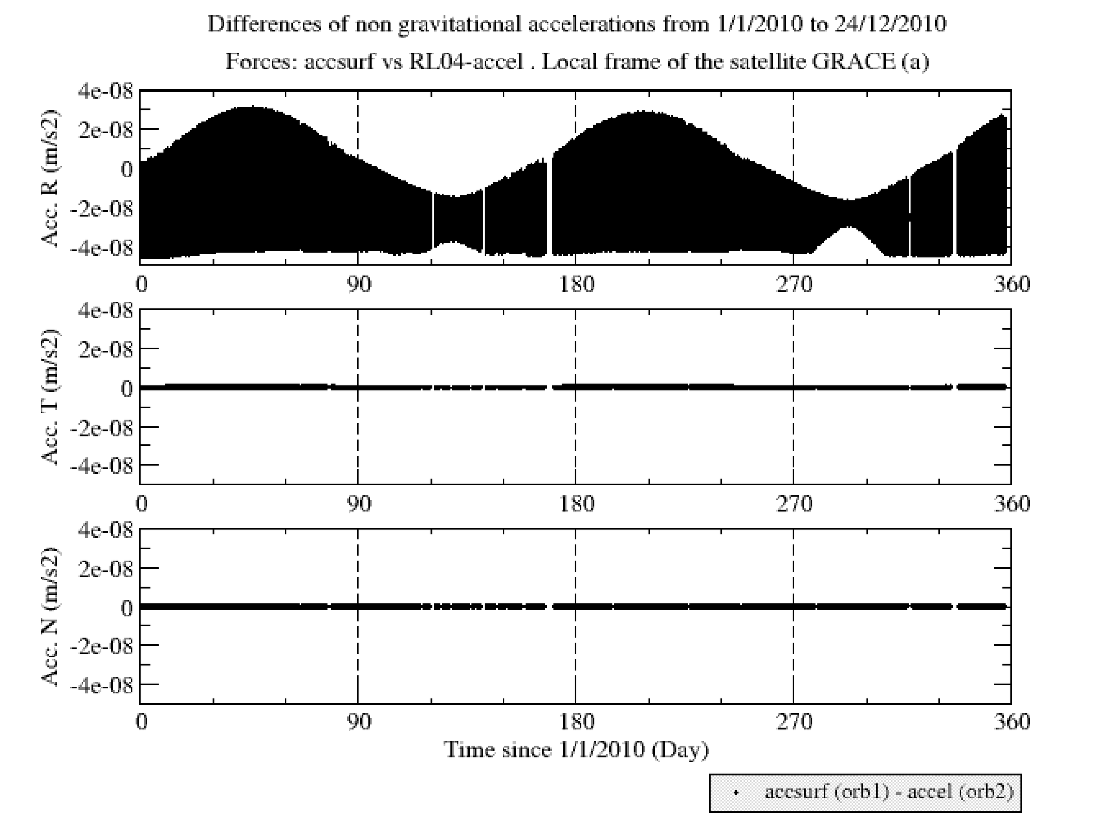

Figure 5: *Results of one year orbit difference between satellite GRACE surface accelerations (using ECMWF albedo model) and GRACE RL04 orbits based on GPS and accelerometer data. In using the radial correction strategy, albedo accelerations represent the main force effect on the radial axis.*

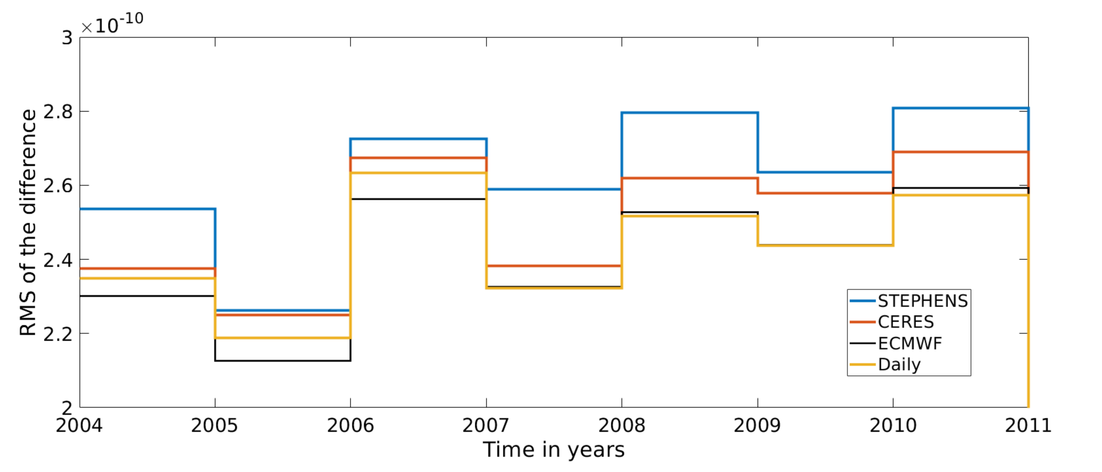

Figure 6: *RMS of the difference between the accelerations due to four albedo models and the RL04.*

5. Conclusions and prospects

- The comparisons using GINS to calibrate the albedo models based on RL04 orbits as reference show that our new Mean model based on ECMWF grids provide the lowest level of RMS, on each of the tested orbits.
- GRACE satellites: using radial correction strategy provides a direct precise comparison of albedo and Infrared models.
- The origin of seasonal and average values differences that appear between the various sets has to be clarified.
- Intensive systematic tests covering the full period 2000-2017 (and in particular from 2012) will be completed soon.

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