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Benchmark data for verifying background model implementations in orbit and gravity field determination software

COST-G
Combination Service for Time-variable Gravity Models

Introduction

As in many other satellite-related sciences, the correct application of background models plays a crucial role in gravity field and orbit determination. The evaluation and application of these models is a potential error source that is difficult to trace back in larger software packages, therefore, we come up with a set of accelerations as benchmark data. These are accelerations derived from models evaluated along a one day orbit arc of GRACE that are typically applied in orbit and gravity field modelling. The benchmark data is compiled with the GROOPS software by the Institute of Geodesy (IfG) at Graz University of Technology. It is intended to be used as a reference data set and provides the opportunity to test the implementation of these models at various analysis centres as it is currently being done in the frame of the Combination Service for Time-Variable Gravity Fields (COST-G).

The accelerations we consider in the benchmark data are:

force	model	remark	magnitude
gravity field	EIGEN-6C4[1]	$d/o = 2 \ldots 180$	$\sim 10^{-2}$ m/s^2
3rd body attractions	DE421[2]	Sun, Moon, Planets	$\sim 10^{-6}$ m/s^2
solid Earth tides	IERS 2010 conv.[3]	anelastic	$\sim 10^{-7}$ m/s^2
ocean tides	EOT11a[4] (FES2014b also avail.)	$d/o = 2 \ldots 120$ w/ and w/o admittances	$\sim 10^{-7}$ m/s^2
dealiasing	AOD1B RL06[5]	$d/o = 2 \ldots 180$	$\sim 10^{-8}$ m/s^2
relativistic correction	IERS 2010 conv.		$\sim 10^{-8}$ m/s^2
pole tides	IERS 2010 conv.		$\sim 10^{-8}$ m/s^2
ocean pole tides	IERS 2010 conv. (Desai)	$d/o = 2 \ldots 180$	$\sim 10^{-9}$ m/s^2
atmospheric tides	AOD1B RL06	$d/o = 2 \ldots 180$	$\sim 10^{-9}$ m/s^2

All accelerations are expressed in the celestial reference frame. As the definition of frames may vary between different software packages (J2000, true system of epoch), the orbit is given in terrestrial and celestial reference frame and additionally, the rotation between the the two frames is listed in the data set. The additional data consists of

Earth rotation	quaternions or rotation matrix
interpolated EOPs	EOP 14 C04[6]
Doodson arguments fundamental arguments	

The complete data set can be found at

ftp://ftp.tugraz.at/outgoing/ITSG/COST-G/softwareComparison/

including a description of the data and how the models are employed in the reference in **00README_simulation.txt**. It enables a comparison of the background force model implementation and may serve as a reference for the handling of celestial and terrestrial reference frames by evaluating the models at the given orbital positions in different software packages. A large difference to the reference accelerations may indicate potential implementation problems.

[1]Förste et al. (2014)
[2]Folkner et al. (2009)
[3]Petit and Luzum (2010)
[4]Savcenko et al. (2011)
[5]Dobslaw et al. (2018)
[6]Bizouard et al. (2018)

What can be done with the data?

The data is intended to enable easy comparisons between software packages, especially in view of detecting errors in the implementation of the background force models.
To show the effect of a minor implementation error we take solid Earth tides, modelled as given in the IERS 2010 conventions. Frequency dependent corrections (referred as 'Step 2' in the conventions) need to be applied to the coefficients of degree two to account for deviations from nominal constant of k_{21}. The formulas (IERS conventions 2010, 6.8a and 6.8b) read as

$$\mathrm{Re}\sum_{f(2,0)}(A_0\delta k_f H_f)e^{i\theta_f} = \mathrm{Re}\sum_{f(2,0)}[(A_0 H_f \delta k_f^R)\cos\theta_f - (A_0 H_f \delta k_f^I)\sin\theta_f] \quad (1)$$

and

$$\Delta\bar{C}_{2m} - i\Delta\bar{S}_{2m} = \eta_m \sum_{f(2,m)}(A_m \delta k_f H_f)e^{i\theta_f}. \quad (2)$$

Assuming an error in the interpretation of the signs marked in green, i.e. taking $+$ instead of the given $-$, leads to non-negligible differences at the level of 2 nm/s^2 in the accelerations along the provided GRACE orbit, shown in Fig. 1.

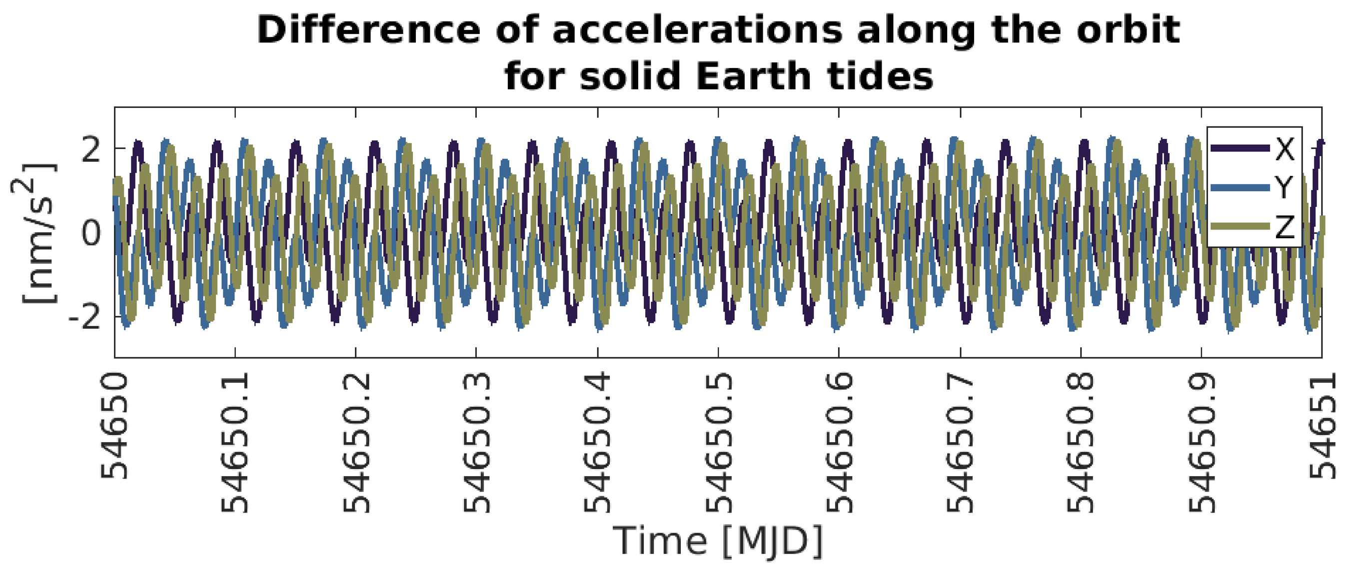

Figure 1: Difference between the reference accelerations for the example effect of solid Earth tides and the evaluation with wrong signs in the degree two corrections.

Although, the magnitude of these differences is minor and only degree two coefficients are affected, it is visible in a monthly GRACE gravity field solution (Fig. 2), resulting in a difference of ~ 1 mm geoid heights.

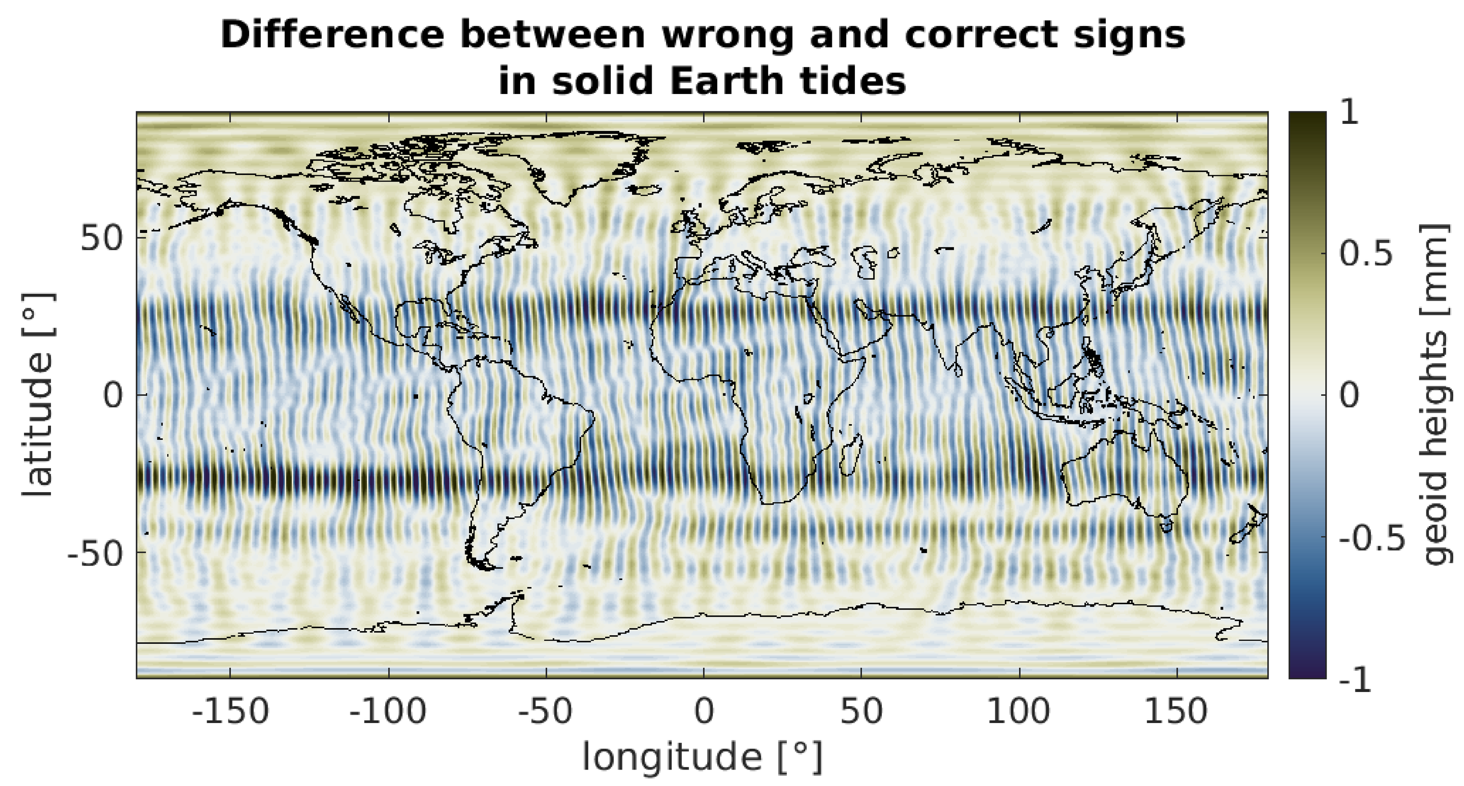

Figure 2: Difference between monthly gravity field solutions calculated with solid Earth tides using wrong and correct signs in the corrections of degree two.

Comparisons within COST-G

In the framework of COST-G gravity field solutions from different analysis centres (AC) and candidate analysis centres are combined to provide a consolidated solution of improved quality to the user. To augment the combination effort, all contributing groups performed a comparison with the benchmark data using their own software packages. This includes the software

- GROOPS - created the reference
- GRACE-SIGMA, Institut für Erdmessung (IfE), Leibniz University of Hannover (LUH)
- GRASP, Institut für Erdmessung (IfE), Leibniz University of Hannover (LUH)
- Bernese GNSS software, Astronomical Institute of the University of Bern (AIUB)
- EPOS, German Research Centre for Geosciences (GFZ)
- GINS, Groupe de Recherche de Géodésie Spatiale (GRGS)

The limit for the difference in evaluating the models along the reference orbit was set to 10^{-11} m/s^2, thus, at least one order of magnitude lower than the accelerometer noise of GRACE. The performance is shown in Fig. 3.

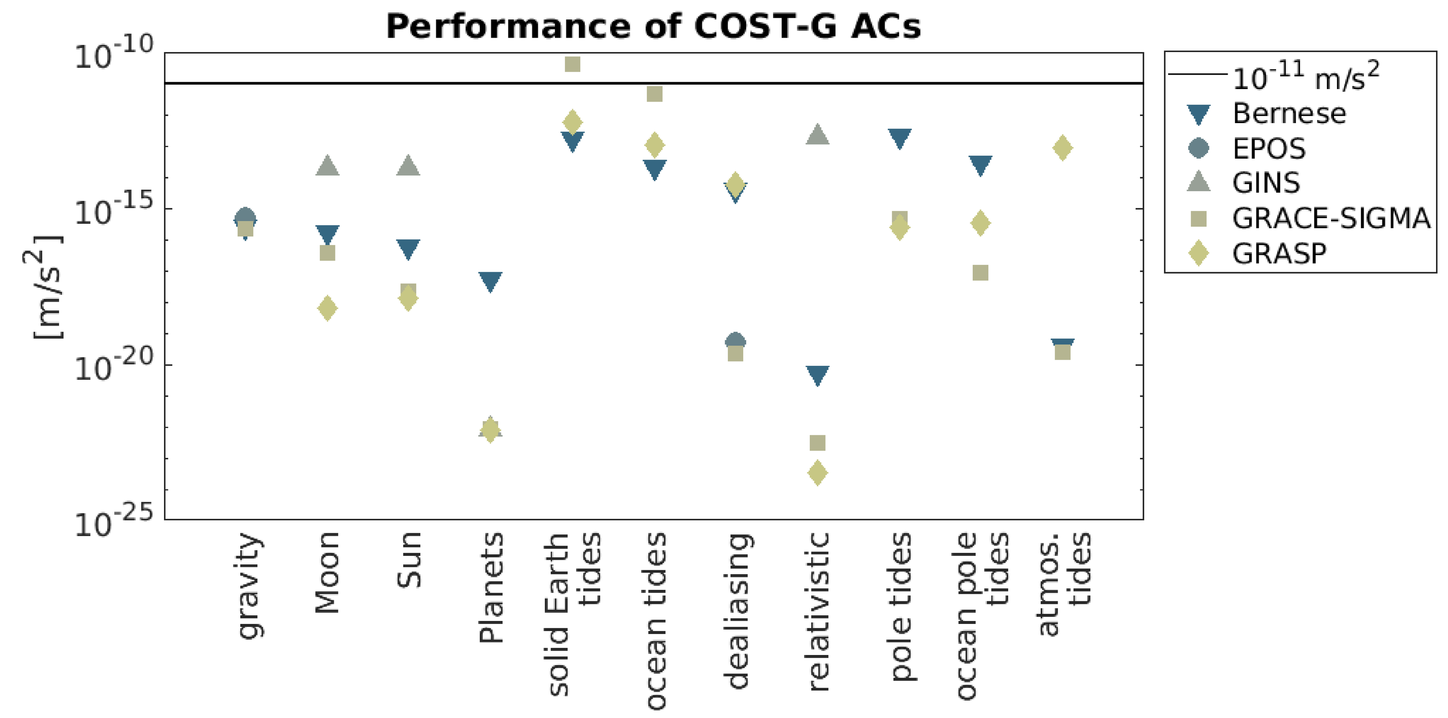

Figure 3: Average of the L^2-norm of the difference between the reference and the evaluation by the respective software of the COST-G ACs for each force considered in the benchmark data set.

With one exception in the solid Earth tides all COST-G ACs and candidate ACs fulfill the requirement of 10^{-11} m/s^2.

Summary

We test and publish benchmark data of forces commonly used for gravity field and orbit determination purposes. The data set consists of orbital positions and forces evaluated along this trajectory. It is intend to enable fundamental software comparisons and bug detection.
The benchmark data was examined with the software used in the COST-G service. These packages agree with each other in the usage of the background models at a level of less than 10^{-11} m/s^2.

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