EIGEN-6S4

A time-variable satellite-only gravity field model to d/o 300 based on LAGEOS, GRACE and GOCE data from the collaboration of GFZ Potsdam and GRGS Toulouse

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Introduction

- GFZ Potsdam and GRGS/CNES Toulouse have a long-time close cooperation in the field of global gravity field determination using satellites which presently focuses among others on “mean” time variable gravity field models** using GRACE and GOCE data.

- EIGEN-6S* (published 2011) was the first “mean” time variable global gravity field model (satellite-only)

- The first upgrade EIGEN-6C2 has been published in 2012, it’s a time variable combined gravity field model

- The next upgrade EIGEN-6S2 (2014) is a satellite-only model, which contains yearly drift parameters for the first time

- The new satellite-only model EIGEN-6S4 is subject of this presentation and will be published soon.

* EIGEN = European Improved Gravity model of the Earth by New techniques

** ”mean” time variable gravity field model = approximate representation of the GRACE temporal variation of the Earth gravity field in one data set.
### Main characteristics/differences of EIGEN-6S2 and EIGEN-6S4

<table>
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<tr>
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<tbody>
<tr>
<td>Maximum degree/order</td>
<td>260</td>
<td>300</td>
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<tr>
<td>LAGEOS-1 and -2 SLR data</td>
<td></td>
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<tr>
<td>GRACE:</td>
<td>GRGS RL02</td>
<td>GRGS RL03 version 2</td>
</tr>
<tr>
<td>GPS-SST &amp; K-band range-rate</td>
<td>200303 - 201012</td>
<td>200208 – 201407</td>
</tr>
<tr>
<td>Max included d/o GRACE</td>
<td>130</td>
<td>130</td>
</tr>
<tr>
<td>Max d/o of the time variable parameters</td>
<td>50</td>
<td>80</td>
</tr>
<tr>
<td>GOCE SGG</td>
<td></td>
<td></td>
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<tr>
<td>– processed by the direct approach (GFZ/GRGS within the GOCE High Level Processing Facility)</td>
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<tr>
<td>– individual normal equations for each SGG component</td>
<td></td>
<td></td>
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<tr>
<td>– application of (120 – 8 resp. 100 – 8) sec band pass filters for all SGG components</td>
<td>350 days $T_{xx}$ $T_{yy}$ $T_{zz}$ out of 20091101 – 20110419 (i.e. the GOCE data of DIR-4)</td>
<td>nominal orbit altitude: 837 days $T_{xx}$ $T_{yy}$ $T_{zz}$ $T_{xz}$ out of 20091101 – 20120801 + lower orbit phases: 422 days $T_{xx}$ $T_{yy}$ $T_{zz}$ $T_{xz}$ out of 20120801 – 20131020 (i.e. the GOCE data of DIR-5)</td>
</tr>
</tbody>
</table>
Combination scheme of the normal equations for EIGEN-6S4

Application of external gravity field information over the polar gaps
For EIGEN-6S4: GRACE/LAGEOS to d/o 130 + zero coefficients to d/o 300
  Algorithm: Spherical cap regularization (Metzler & Pail 2005)

All coefficients to d/o 80 were finally replaced by time variable parameters
which have been separately derived from the time series of monthly GRACE solutions from CNES/GRGS RL03-v2
Basis of the time-variable coefficients:

- The time-variable parameters in EIGEN-6S4 are based on the time series of monthly GRACE solutions from CNES/GRGS: **RL03-v2**
- **RL03-v2** spans from August 2002 to July 2014
- It includes GRACE GPS & KBR data, and Lageos-1 and Lageos-2 SLR data
- **RL03-v2** is complete to degree and order 80. It is obtained from a inversion by Cholesky decomposition for degrees 1 and 2 and from a truncated SVD inversion for the rest of the parameters.
Conversion from time series to mean field:

- The time variable parameters for EIGEN-6S4 are obtained by regression on the \textit{RL03 v2} time series. For each coefficient \( C/S(l,m) \) the mean model consists in:
  - One bias and one drift / year
  - One annual and one semi-annual Sine and Cosine adjusted over the complete time span
  - The resulting curve is continuous, except in the case of major earthquakes where a break is introduced

For EIGEN-6S and EIGEN-6C2 (as well as for GOCC05S):
- One bias and one drift over the complete time span

Degree 2: Thanks to the inclusion of Lageos-1 and Lageos-2, the deterministic modelling of degree 2 to can be extended to 1985-2014.

Extrapolation strategy before and beyond the measurement time span:
- The slope of the coefficients is more or less unpredictable outside of the data span (1985-2014 for degree 2, 2002-2014 for the other coefficients)
  - as a consequence, a zero-slope assumption in extrapolation has been chosen (conservative option).
- The annual and semi-annual signals are much more stable than the slope
  - they are kept in extrapolation
Examples for time variable spherical harmonic coefficients in EIGEN-6S4
Example for the temporal behaviour of the spherical harmonics coefficients: $C_{30}$

The Sumatra earthquake had obviously almost no impact on $C_{30}$.

Zero slope assumption outside the measurement timespan.

Earthquake Japan 2011
Earthquake Chile 2010
Example for the temporal behaviour of the spher. harm. coefficients: $C_{30}$
Example for the temporal behaviour of the spherical harmonic coefficients: $C_{30}$
Example for the temporal behaviour of the spher. harm. coefficients: $C_{30}$
Example for the temporal behaviour of the spher. harm. coefficients: $C_{20}$
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Evaluation of EIGEN-6S4

→ Orbit computation for GOCE, CHAMP and JASON-2
GOCE Orbit adjustment tests

- Observations: Kinematic GOCE (Bock et al. 2011) orbit positions
- Dynamic orbit computation
- **GOCE: 60 arcs** (01.11. – 31.12.2009). Arclength = **1.25 days**

**Parametrization for GOCE:**
- Accelerometer **biases**: 2/rev for cross track / radial / along track
- Accelerometer **scaling factor**: along track fixed (set to 1.0). 1/arc for cross track / radial

Rms values [cm] of the orbit fit residuals (mean values from the 60 resp. 75 arcs)

<table>
<thead>
<tr>
<th>Gravity field model</th>
<th>GOCE max. d/o 180 x 180</th>
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<tbody>
<tr>
<td>EGM2008 (Pavlis et al. 2012)</td>
<td>2.70</td>
</tr>
<tr>
<td>GIF48 (Ries et al. 2011)</td>
<td>1.64</td>
</tr>
<tr>
<td>GOCO03S (Mayer-Gürr et al. 2012)</td>
<td>1.64</td>
</tr>
<tr>
<td>EIGEN-6C4</td>
<td>1.50</td>
</tr>
<tr>
<td>GO_CONS_GCF_2_TIM_R5</td>
<td>1.52</td>
</tr>
<tr>
<td>GO_CONS_GCF_2_DIR_R5</td>
<td>1.51</td>
</tr>
<tr>
<td>EIGEN-6S (time variable) at 20091201</td>
<td>1.48</td>
</tr>
<tr>
<td>EIGEN-6S2 (time variable) at 20091201</td>
<td>1.47</td>
</tr>
<tr>
<td>GOCO05S (time variable, Mayer-Gürr 2015) at 20091201</td>
<td>1.42</td>
</tr>
<tr>
<td>EIGEN-6S4 (time variable) at 20091201 (GOCE)</td>
<td>1.43</td>
</tr>
</tbody>
</table>

**Conclusion**

- Clear improvement of the dynamic orbit computation for GOCE when using **time variable** gravity field models
- Best results for the most recent models EIGEN-6S4 and GOCO05S
JASON-2 dynamic orbit computation* - EIGEN-6S2 (as for the J2 GDR-D)

- Temporal behaviour (over ~ 6 years in terms of drift + annual variation) of the radial orbit differences w.r.t. the JPL14A reduced dynamic orbits (where the impact of the gravity field is assumed to be suppressed) = geographically correlated radial orbit error.
- Over the oceans only – to show the erroneous impact on sea level estimation

* By courtesy of A. Couhert and J. Moyard / CNES
JASON-2 dynamic orbit computation*:
- EIGEN-6S4

- Temporal behaviour (over ~ 6 years in terms of drift + annual variation) of the radial orbit differences w.r.t. the JPL14A reduced dynamic orbits (where the impact of the gravity field is assumed to be suppressed) = geographically correlated radial orbit error.
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JASON-2 dynamic orbit computation - CSR RL05 monthly gravity solution*

- Temporal behaviour (over ~ 6 years in terms of drift + annual variation) of the radial orbit differences w.r.t. the JPL14A reduced dynamic orbits (where the impact of the gravity field is assumed to be suppressed) = geographically correlated radial orbit error.
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*The CSR monthly gravity field solution is taken as a reference among the different GRACE analysis centers (CSR, GFZ, JPL, CNES/GRGS).
JASON-2 dynamic orbit computation*:
- EIGEN-6S4 incl. estimation of $C/S_{31}$

- Temporal behaviour (over ~ 6 years in terms of drift + annual variation) of the radial orbit differences w.r.t. the JPL14A reduced dynamic orbits (where the impact of the gravity field is assumed to be suppressed) = geographically correlated radial orbit error.
- Over the oceans only – to show the erroneous impact on sea level estimation

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Conclusion for the JASON-2 dynamic orbit computation

• The new model EIGEN-6S4 reduces the geographically correlated radial orbit drift rate, from more than 1 mm/y (for EIGEN-6S2) to less than 0.6 mm/y over ~ 6 years, with respect to reduced dynamic orbits.

• The improvement is close to the level reached with the CSR monthly GRACE solutions (instead of a mean gravity field model).

• The mean RMS of SLR post-fit residuals also confirm that the dynamic orbits perform better when using EIGEN-6S4.
Summary

- EIGEN-6S4 is a new time-variable global satellite-only gravity field model of maximum d/o 300

- This model has been inferred from the combination of LAGEOS, GRACE and GOCE and is practically a time-variable version of the GOCE DIR-5 model

- EIGEN-6S4 contain time variable parameters for all spher. harm. coeff. up to degree 80 (drift parameters per year, annual and semiannual terms).

- EIGEN-6S4 shows improvements in orbit determination for Earth observation satellites w.r.t. precursor time variable models

- The final version of EIGEN-6S4 will be released mid of 2015 and will be available via the ICGEM data base at GFZ Potsdam

http://icgem.gfz-potsdam.de
Thank you for your attention!