Gravity Field Determination at AIUB: From CHAMP and GRACE to GOCE

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Introduction

CHAMP gravity field recovery using GPS hl-SST
- least-squares adjustment *w/o* empirical error models
- static field (augmented with GOCE GPS)
- time variations (?)

GRACE gravity field recovery using K-band ll-SST
- least-squares adjustment *w/o* empirical error models
- static field
- time variations

GOCE gravity field recovery using gradiometry
- least-squares adjustment *with (?)* empirical error models
- static field
- no time variations

All solutions are computed without applying any regularization
hl-SST-only solutions
Static fields up to degree 120

- GOCE GPS hl-SST data allows it to significantly improve the quality of the „high“ degrees wrt a CHAMP-only gravity field solution

10.1 cm RMS of differences to ITG-GRACE2010

Reference field:
ITG-GRACE2010

Differences:
CHAMP & GOCE
(8 years & 1.7 years)

- the quality of the low to medium degree coefficients is confirmed by external validations
hl-SST-only solutions
Validation up to degree 60

LAGEOS SLR data

Even a slightly better performance for the combined SST-only model than for the GRACE-based models

<table>
<thead>
<tr>
<th>RMS (cm)</th>
<th>EIGEN 5S</th>
<th>ITG 03S</th>
<th>ITG 2010</th>
<th>AIUB CHAMP</th>
<th>CHAMP only</th>
<th>GOCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia (GPS)</td>
<td>13.2</td>
<td>13.2</td>
<td>13.2</td>
<td>13.3</td>
<td>13.2</td>
<td>13.1</td>
</tr>
<tr>
<td>Germany (EUVN)</td>
<td>1.7</td>
<td>1.6</td>
<td>1.8</td>
<td>2.0</td>
<td>1.9</td>
<td>1.8</td>
</tr>
<tr>
<td>Germany (GPS)</td>
<td>2.0</td>
<td>2.0</td>
<td>1.9</td>
<td>2.1</td>
<td>2.1</td>
<td>2.0</td>
</tr>
<tr>
<td>Canada (GPS)</td>
<td>8.4</td>
<td>8.5</td>
<td>8.7</td>
<td>8.7</td>
<td>8.0</td>
<td>8.6</td>
</tr>
<tr>
<td>EUREF (GPS)</td>
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<td>8.9</td>
<td>9.1</td>
<td>9.0</td>
<td>8.9</td>
<td>9.0</td>
</tr>
<tr>
<td>Japan (GPS)</td>
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<td>5.9</td>
<td>5.8</td>
<td>6.1</td>
<td>5.8</td>
</tr>
</tbody>
</table>

Terrestrial Data

Similar validation results for the combined SST-only model as for the GRACE-based models, especially also for the high-quality data sets from Germany.
hl-SST-only solutions

Time variability from CHAMP (1)

- a single monthly CHAMP solution does not really look very promising …

- … but a long time series of data allows it to either
  - solve for periodic and trend functions, or to
  - „stack“ monthly solutions (each January, each February, etc.), and to apply significance tests (up to d/o 10)
Most pronounced time variable signals may be extracted from CHAMP data.
Comparison of time variability

Variations at selected locations from CHAMP vs. GRACE

GFZ and AIUB show a very good agreement in amplitude and phase of the variations.

CHAMP shows a remarkable sensitivity to seasonal and secular mass variations.
GRACE K-band solutions

AIUB-GRACE03S based on 6 years of data

- classical least-squares solution with simultaneously estimated time variations (trends, annual and semi-annual terms up to d/o 30)
- $C_{20}$ cannot be reliably estimated from GRACE K-band data
GRACE monthly solutions

- monthly solutions up to degree 60, background model AIUB-GRACE03S (static part only)
- secular and seasonal variations may be fitted a posteriori to the monthly solutions for analysis
- significance tests for seasonal parameters and trends show sensitivity up to degree 60, but only to a reduced order
- coefficients beyond order 45 are not further estimated, leading to fewer stripes at small smoothing radii

March 2007 (l=60, m=45); 250 km Gauss

Effect of orders > 45
• weighted RMS of the variability over the oceans may be used to compare the quality of the monthly solutions in a simple way
GRACE monthly solutions

Variability over the oceans

Weighted RMS (300 km Gauss smoothed)

60 x 60:
- GFZ
- JPL
- CSR
- AIUB
- ITG

60 x 45:
- AIUB

50 x 50:
- GRGS

Geoid heights (mm)

Year

2003 2004 2005 2006 2007 2008 2009 2010
as opposed to other solutions we use parametric techniques to account for the characteristics of the gradiometer measurements

for each gradiometer component the following parameters are set up (in addition to the SH coefficients up to degree 160)
- one offset and one drift parameter per day
- once-, twice-, and three-times-per-rev (-day) parameters per day

the empirical parameters are pre-eliminated before accumulating the daily normal equations (NEQs) to a combined system
• in addition parameters of a piecewise linear and continuous function are set up for each gradiometer component with a spacing of 1 min

• setting up offset, drift, etc., and the piecewise linear parameters $p_i$ results in a singular NEQ system. The singularity may be removed by
  - pseudo-observations $p_i = 0$ with weights of the order $(\sigma_0 / \sigma_i)^2$
  - $\sigma_0$ and $\sigma_i$ are the user-defined values for the a priori standard deviations of the gradiometer data and the parameters $p_i$

• the most pronounced signals outside the gradiometer measurement bandwidth are captured with this parametrization
• A solution is said to be free, if constraints are only set up to remove the singularities.

• The free solution may be used to calculate empirical covariances (over user-defined time intervals) associated with the
  - residuals of the gradiometer observations of the free solution
  - piecewise linear parameters $p_i$ of the free solution

• These covariance matrices improve the error model for the gradiometer solution, if introduced in a subsequent solution.
GOCE gradiometer analysis

55 days of ZZ data, 3-sec sampling

\[
\begin{pmatrix}
A_1^T A_1 & A_1^T A_2 \\
A_2^T A_1 & A_2^T A_2
\end{pmatrix}
\begin{pmatrix}
x \\
p
\end{pmatrix}
= \begin{pmatrix}
A_1^T l \\
A_2^T l
\end{pmatrix}
\]

\[
\Rightarrow
\begin{pmatrix}
A_1^T A_1 & A_1^T A_2 \\
A_2^T A_1 & A_2^T A_2 + P
\end{pmatrix}
\begin{pmatrix}
x \\
p
\end{pmatrix}
= \begin{pmatrix}
A_1^T l \\
A_2^T l
\end{pmatrix}
\]

Very flexible handling of emp. covariances on the level of normal equations
GOCE gradiometer analysis
71 days of XX, YY, ZZ data, 1-sec sampling

Reference field:
ITG-GRACE2010

Differences:
Gradio-only
Gradio & GPS
constr. 2nd deriv.
Time-wise solution

Promising performance compared to the time-wise model from release-1
GOCE gradiometer analysis
Impact of data accumulation, 1-sec sampling

Reference field:
ITG-GRACE2010

Differences:
AIUB (2 months)
AIUB (8 months)
Time-wise solution

Similar performance as the time-wise model from release-2
Conclusions

- High-quality SST-only solutions may be computed with CHAMP and GOCE GPS data
  - CHAMP even allows to recover the most pronounced time variable signals due to the long data series available
- GRACE static solutions up to degree and order 160 are computed with simultaneously solved for time variations
  - Based on sensitivity analyses the monthly fields are solved up to degree 60 and order 45
- GOCE static solutions based on a parametric approach are so far computed up to degree and order 160
  - Empirical covariances are either derived from the residuals of the free solution, or from the piecewise linear parameters co-estimated with the free solution. A similar performance may be obtained by constraining subsequent differences of piecewise linear parameters