EIGEN-6

A new combined global gravity field model including GOCE data from the collaboration of GFZ-Potsdam and GRGS-Toulouse

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Data used for EIGEN-6S/C

LAGEOS-1/2 SLR data
GRACE GPS-SST and K-band range-rate data:
- January 2003 ... June 2009 (6.5 years)
- within the GRGS RL02 GRACE processing
- normal equations including 5 time variable parameters for each spherical harmonic coefficient up to degree 50:
  \[ G(t) = G(t_0) + \text{DOT}(t - t_0) + C1A \cos(\omega_a(t - t_0)) + S1A \sin(\omega_a(t - t_0)) + C2A \cos(\omega_s(t - t_0)) + S2A \sin(\omega_s(t - t_0)) \]
  with \( t_0 = 2005.0 \) = reference epoch
  where \( \text{DOT} \) = drift
  \( C1A, S1A \) = annual terms
  \( C2A, S2A \) = semi-annual terms

GOCE:
- November 2009 ... June 2010 (6.7 months)
- GOCE SGG data: Txx, Tyy and Tzz
- processed by the direct approach (GFZ/GRGS within GOCE-HPF)
- individual normal equations for each SGG component
- applying a 100–8 sec band pass filter for all three SGG components
  - The SGG signal is filtered-out below degree ~ 50

Terrestrial data:
DTU10 global gravity anomaly grid (Andersen, Knudsen and Berry 2010 & Anderson 2010)
  - This is obtained from altimetry over the oceans and EGM2008 over land

The combination of the different satellite and surface parts has been done by a band-limited combination of normal equations, which are obtained from observation equations for the spherical harmonic coefficients.
Combination scheme of EIGEN-6C

Accumulation of a **full normal matrix** up to d/o 370:
~170 000 parameters (~2 000 000 up to degree 1420)

- **contribution to the solution:**
- **kept separately:**

Separate block diagonal solution:

**Spherical harmonic degree**

<table>
<thead>
<tr>
<th>Degree</th>
<th>LAGEOS</th>
<th>GRACE</th>
<th>GOCE SGG Txx + Tyy + Tzz</th>
<th>DTU10 gravity anomaly data</th>
<th>DTU10, block diagonal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2, 30</td>
<td>130</td>
<td>160</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>240</td>
<td>260</td>
<td>370</td>
<td></td>
<td></td>
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<tr>
<td>1420</td>
<td></td>
<td></td>
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</tbody>
</table>

**Resolution:**
- 125km/1.1deg
- 83km/.75deg
- 54km/.49deg
- 14km/.13 deg.
GOCE Orbit adjustment tests

• Observations: \texttt{GO\_CONS\_SST\_PKI\_2I} (kinematic GOCE orbit positions)
• Dynamic orbit computation
• 60 arcs (November-December 2009), arc length = 1.25 days
• Accelerometer parameterization:
  - biases: twice per rev for cross track / radial / along track
  - scaling factors: along track fixed (set to 1.0), once per arc for cross track / radial

\textbf{Rms values [cm] of the orbit fit residuals (mean values from the 60 arcs)}

\begin{table}[h]
\centering
\begin{tabular}{|l|c|c|c|}
\hline
Gravity field model / max. d/o & 120x120 & 150x150 & 180x180 \\
\hline
EGM2008 & 4.0 & 2.9 & 2.8 \\
GGM03C & 3.6 & 2.4 & 2.3 \\
EIGEN-5C & 3.4 & 2.3 & 2.2 \\
EIGEN-51C & 3.2 & 2.0 & 1.8 \\
ITG-GRACE2010S & 3.3 & 1.8 & 1.7 \\
\texttt{GO\_CONS\_GCF\_2\_DIR} & 3.9 & 2.6 & 2.4 \\
GOCO02S & 3.2 & 1.8 & 1.6 \\
EIGEN-6S (epoch 01.12.2009) & 3.2 & 1.6 & 1.5 \\
EIGEN-6C (epoch 01.12.2009) & 3.2 & 1.6 & 1.5 \\
\hline
\end{tabular}
\caption{Rms values [cm] of the orbit fit residuals (mean values from the 60 arcs)}
\end{table}

\textbullet{} The best orbit fits for maximum degree 180 for all models

\textbullet{} GOCE-GRACE models give better results than GRACE models
Orbit adjustment tests (2)

Mean RMS: SLR and PRARE in cm, PRARE-Doppler and DORIS in mm/sec
All gravity field models truncated to 120x120

Satellite   Data   #arcs type | Data   | GGM03C | ITG-2010S | EIGN-5C | EGM2008 | GOCC02S | EIGN-6C |
------------|---------|--------|---------|---------|---------|---------|---------|
GFZ-1       5x3 days     SLR   | GGM03C | 14.05   | 13.96   | 14.10   | 14.70   | 14.0    | 13.97   |
STELLA      5x3 days     SLR   | GGM03C | 2.91    | 2.98    | 2.92    | 2.92    | 2.87    | 2.87    |
STARLETTE   5x3 days     SLR   | GGM03C | 2.81    | 2.55    | 2.53    | 2.54    | 2.52    | 2.41    |
AJISAI      5x3 days     SLR   | GGM03C | 3.38    | 3.26    | 3.15    | 3.18    | 3.18    | 3.15    |
LAGEOS-1    5x6 days     SLR   | GGM03C | 1.04    | 1.19    | 1.01    | 1.02    | 1.01    | 1.00    |
LAGEOS-2    5x6 days     SLR   | GGM03C | 1.02    | 1.32    | 1.02    | 1.01    | 1.02    | 1.01    |
ERS-2       6x6 days     SLR   | EIGN-5C | 5.36    | 5.39    | 5.29    | 5.31    | 5.29    | 5.28    |
PHARE      6x6 days     PRARE | EIGN-5C | 3.56    | 3.53    | 3.54    | 3.56    | 3.53    | 3.54    |
PDO         6x6 days     PDO   | EIGN-5C | 0.344   | 0.346   | 0.343   | 0.345   | 0.342   | 0.343   |
ENVISAT      7x4...8 days SLR   | EIGN-5C | 4.27    | 4.54    | 4.49    | 4.27    | 4.47    | 4.41    |
DORIS       7x4...8 days DORIS | EIGN-5C | 0.495   | 0.496   | 0.496   | 0.495   | 0.496   | 0.495   |
WESTPAC     5x6 days     SLR   | EIGN-5C | 4.11    | 4.12    | 4.12    | 4.27    | 4.05    | 4.10    |
JASON       5x6 days     SLR   | EIGN-5C | 1.83    | 1.88    | 1.82    | 1.84    | 1.80    | 1.78    |

The best orbit fits overall were obtained with the new models which include GOCE data
Geoid-Height Differences between:
EIGEN-6C and EGM2008

EIGEN-6C „corrects“ EGM2008
→ mainly over continent parts with bad terrestrial data coverage

EGM2008 vs. EIGEN-6C max 1400
ζ, 0.2° x 0.2°
w rms about mean / min / max = 0.1146 / -2.729 / 2.553 meter
Geoid-Height Differences between:
EIGEN-6C and EGM2008
at the South Polar Region

EIGEN-6C "corrects" EGM2008
in Antarctica
(outside the GOCE polar gap)

griddiff
\( \zeta \), 0.2° x 0.2°
wrms about mean / min / max = 0.1741 / -0.9398 / 1.194 meter
Residual Dynamic Ocean Topography (non-filtered):
EGM2008 – (MSSH/GFZ - ECCO)

EGM2008 vs. MSSH/ECCO
ζ, 0.5° x 0.5°
wrms about mean / min / max = 0.2253 / -2.383 / 3.193 meter
Residual Dynamic Ocean Topography (non-filtered): EIGEN-6C – (MSSH/GFZ - ECCO)

EIGEN-6Cp08–MSSH/ECCO
ζ, 0.5° x 0.5°

wrms about mean / min / max = 0.1842 / -2.662 / 3.087 meter
The trend of (normalized) $C_{20}$ in EIGEN-6S/C

IERS conventions: $11.6 \times 10^{-12}$
becoming rounder

EIGEN-6S/C: $-12.6 \times 10^{-12}$
becoming flatter
Time variability of $C_{20}$

$C(2,0)$ difference to $-0.00048416525$

- LAGEOS-1+2 (only degree 2 is solved)
- GRACE + LAGEOS-1+2 (10-day time series from GRGS)
- actual EIGEN-6S (GRACE + GOCE + LAGEOS-1+2)
- proposed EIGEN-6S (C20_DOT and 18.6 year tide corrected)

Change of the trend of $C_{20}$

EIGEN-6 data time span
Time variability of $C_{20}$

$C(2,0)$ difference to $-0.00048416525$

- Proposal (black curve): Empirically corrected values for $C_{20}$
  - $C_{20}$-trend: $\sim +3.2 \times 10^{-12}$
  - the 18.6 year tide: $\sim 0.32$ cm
  (could be expressed as an additional time variable $C_{20}$ correction)
Summary / Conclusion

- **EIGEN-6S** is new satellite-only model from LAGEOS, GRACE & GOCE data (up to deg. 240).
- **EIGEN-6C** is a new combined gravity field model from the EIGEN-6S satellite data and the DTU10 global gravity anomaly grid of a **maximum degree 1420**.
- **Over land and beyond degree 240**, EIGEN-6C is in principle a reconstruction of EGM2008 (due to the inclusion of DTU10)
- EIGEN-6S/C contain **time variable parameters** for all spherical harmonic coefficients **up to degree 50** (drift, annual and semi-annual terms).

- EIGEN-6S/C has been published on the ICGEM data base at GFZ Potsdam:  
  [http://icgem.gfz-potsdam.de](http://icgem.gfz-potsdam.de)

  We plan to release a second version of EIGEN-6C soon (December 2011)
  - adding 2 more years of GRACE SST and KBR data
  - using data from the full time span of the GOCE nominal mission (Nov. 2009 – Apr. 2011)
  - including corrected values for the time variable parameters of $C_{20}$
  - extended to a higher maximum degree/order (up to degree/order ~1900)

  For consistency we advise to adopt the same model for orbit computation and geoid reference (time variable parts affect mainly the geoid over continents)