EIGEN-5C:
The new GeoForschungsZentrum Potsdam / Groupe de Recherche de Géodésie Spatiale combined gravity field model

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# Overview over the GFZ/CNES combined gravity field models released during the last years

<table>
<thead>
<tr>
<th>EIGEN-CG01C</th>
<th>EIGEN-CG03C</th>
<th>EIGEN-GL04C</th>
<th>EIGEN-5C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution:</td>
<td>360 x 360</td>
<td>360 x 360</td>
<td>360 x 360</td>
</tr>
</tbody>
</table>

## Main differences:

### Satellite data

<table>
<thead>
<tr>
<th>Satellite</th>
<th>CHAMP</th>
<th>GRACE</th>
<th>LAGEOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 days:</td>
<td>./</td>
<td>02/2003 - 07/2004</td>
<td>./</td>
</tr>
</tbody>
</table>

### Ocean data (direct altimetry)

<table>
<thead>
<tr>
<th>Ocean data</th>
<th>CLS01 sea surface heights</th>
<th>GFZ mean sea surface heights</th>
</tr>
</thead>
</table>

### Maximum degree of the full normal matrix

- 140
- 140
- 179
- 280

### Overlapping range [deg] between satellite and terrestrial data:

- 70 … 109
- 70 … 120
- 70 … 115
- 70 … 150

### Terrestrial data: Grid size for the full normal equations

- 1° x 1°
- 1° x 1°
- 30’ x 30’
- 30’ x 30’

### Remarks:

- including the latest ArcGP data (Forsberg 2006)
- New data of Europe and Australia
Surface data sets used for EIGEN-5C

1. Arctic Gravity Project (ArcGP) gravity anomalies (Forsberg 2006), for regions of latitude > 64°, resolution 5’ x 5’
2. NRCan gravity anomalies (Véronneau 2003), resolution 2’ x 2’
3. AWI (Studinger 1988) and LDO (Bell et al., 1999) gravity anomalies resolution higher than 5’ x 5’
4. NGA altimetric gravity anomalies for regions in the oceans (and adjacent seas) which are not covered by the GFZ-geoid, resolution 30’ x 30’, including standard deviations,
5. Marine geoid undulations from GFZ MSSH (resolution 2’ x 2’) minus ECCO sea surface topography
6. NGA terrestrial gravity anomalies (if not covered by data sets 1 to 3), resolution 30’ x 30’
7. NGA ship-borne gravity anomalies over water depths less than 2000 m, resolution 1° x 1°
8. Gravity anomalies of Europe, resolution 15’ x 15’ (H. Denker, IfE Hannover, 2007)
9. Gravity anomalies of East Europe, resolution 30’ x 30’ (H. Denker, IfE Hannover, 2007)
10. Gravity Anomaly data of the Australian Region, point data, resolution higher than 5’ x 5’

The NGA data sets (Kenyon, Pavlis 1997) are those already incorporated in the EGM96 solution. Data gaps were filled with the satellite-only model EIGEN-5S (white areas)
Combination scheme of EIGEN-5C

contribution to the solution, full normal matrix:
kept separately and bound together with the surface data using constraints**):
kept separately (reduced from the full normal matrix):
not used (low-pass filtered in order to avoid truncation errors):

contribution to the solution, block diagonal matrix:

contribution to the solution, numerical integration:

**) constraints (pseudo observations), applied between degree 90 and 150:

\[
\frac{C}{S_{nm_{\text{Surface}}}} - \frac{C}{S_{nm_{\text{GRACE}}}} + \text{LAG.} = 0 \pm \sigma
\]

\[
\sigma = 0.8696 \cdot 10^{10} \cdot e^{(l-90)/11.8}
\]
EIGEN-5C: Degree variances (in terms of geoid heights) in comparison to previous EIGEN-models

Normal equation overlapping range for EIGEN-5C
EGM2008 vs. EIGEN-5C

ITG-GRACE03S vs. EIGEN-5C

Overweighting of the terrestrial data?

EIGEN-5S vs. GGM03S

EIGEN-5C: Degree variances (in terms of geoid heights) in comparison to other current models including EGM2008
Orbit adjustment tests (1): CHAMP and GRACE

SLR residuals (cm) after an orbit determination based on GPS (CHAMP, GRACE) and K-Band Range-Rate (GRACE) data. The SLR data were not included for the orbit adjustment!

Data: three 1.5 day arcs per satellite,
Included SLR normal points: GRACE: 592
CHAMP: 358

<table>
<thead>
<tr>
<th>Satellite</th>
<th>truncation</th>
<th>GGM02C</th>
<th>GGM03S</th>
<th>ITG-GRACE03S</th>
<th>EGM2008</th>
<th>EIGEN-GL04C</th>
<th>EIGEN-5S</th>
<th>EIGEN-5C</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHAMP</td>
<td>120 x 120</td>
<td>5.32</td>
<td>5.45</td>
<td>5.38</td>
<td>5.51</td>
<td>5.44</td>
<td>5.56</td>
<td>5.59</td>
</tr>
<tr>
<td></td>
<td>150 x 150</td>
<td>5.19</td>
<td>5.44</td>
<td>5.30</td>
<td>5.46</td>
<td>5.41</td>
<td>5.58</td>
<td>5.52</td>
</tr>
<tr>
<td>GRACE</td>
<td>120 x 120</td>
<td>5.50</td>
<td>5.28</td>
<td>5.39</td>
<td>5.46</td>
<td>5.25</td>
<td>5.16</td>
<td>5.15</td>
</tr>
<tr>
<td></td>
<td>150 x 150</td>
<td>5.54</td>
<td>5.27</td>
<td>5.38</td>
<td>5.43</td>
<td>5.24</td>
<td>5.19</td>
<td>5.14</td>
</tr>
</tbody>
</table>
## Orbit adjustment tests (2): SLR- and other satellites

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

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Data #arcs</th>
<th>Data Typ</th>
<th>GGM02C</th>
<th>GGM03S</th>
<th>EIGEN-GL04C</th>
<th>ITG-GR03S</th>
<th>EGM2008</th>
<th>EIGEN-5S</th>
<th>EIGEN-5C</th>
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</thead>
<tbody>
<tr>
<td>GFZ-1</td>
<td>5x3 days</td>
<td>SLR</td>
<td>14.31</td>
<td>13.86</td>
<td>13.78</td>
<td>14.11</td>
<td>14.67</td>
<td>13.78</td>
<td>14.10</td>
</tr>
<tr>
<td>STELLA</td>
<td>5x3 days</td>
<td>SLR</td>
<td>3.24</td>
<td>2.91</td>
<td>2.97</td>
<td>3.01</td>
<td>2.97</td>
<td>2.92</td>
<td>2.92</td>
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<tr>
<td>STARLETTE</td>
<td>5x3 days</td>
<td>SLR</td>
<td>2.45</td>
<td>2.81</td>
<td>2.56</td>
<td>2.57</td>
<td>2.56</td>
<td>2.53</td>
<td>2.53</td>
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<tr>
<td>AJISAI</td>
<td>5x3 days</td>
<td>SLR</td>
<td>3.18</td>
<td>3.37</td>
<td>3.16</td>
<td>3.15</td>
<td>3.19</td>
<td>3.15</td>
<td>3.15</td>
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<tr>
<td>LAGEOS-1</td>
<td>5x6 days</td>
<td>SLR</td>
<td>1.13</td>
<td>1.03</td>
<td>1.13</td>
<td>1.13</td>
<td>1.15</td>
<td>1.01</td>
<td>1.01</td>
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<tr>
<td>LAGEOS-2</td>
<td>5x6 days</td>
<td>SLR</td>
<td>1.05</td>
<td>1.02</td>
<td>1.05</td>
<td>1.05</td>
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<td>1.02</td>
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<tr>
<td>ERS-2</td>
<td>6x6 days</td>
<td>SLR</td>
<td>5.86</td>
<td>5.34</td>
<td>5.34</td>
<td>5.34</td>
<td>5.35</td>
<td>5.29</td>
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<td></td>
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<td>3.86</td>
<td>3.54</td>
<td>3.56</td>
<td>3.55</td>
<td>3.58</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>0.371</td>
<td>0.343</td>
<td>0.346</td>
<td>0.344</td>
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<tr>
<td>ENVISAT</td>
<td>7x4…8 days</td>
<td>SLR</td>
<td>4.30</td>
<td>4.27</td>
<td>4.38</td>
<td>4.20</td>
<td>4.20</td>
<td>4.48</td>
<td>4.49</td>
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<tr>
<td></td>
<td></td>
<td>DORIS</td>
<td>0.495</td>
<td>0.495</td>
<td>0.496</td>
<td>0.495</td>
<td>0.495</td>
<td>0.496</td>
<td>0.496</td>
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<tr>
<td>WESTPAC</td>
<td>5x6 days</td>
<td>SLR</td>
<td>4.21</td>
<td>4.09</td>
<td>3.97</td>
<td>3.98</td>
<td>3.97</td>
<td>4.12</td>
<td>4.12</td>
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<tr>
<td>JASON</td>
<td>SLR</td>
<td></td>
<td>1.89</td>
<td>1.83</td>
<td>1.88</td>
<td>1.87</td>
<td>1.89</td>
<td>1.82</td>
<td>1.82</td>
</tr>
</tbody>
</table>
### GPS/Leveling test

Comparison with geoid heights determined point-wise by GPS positioning and leveling:

- Root mean square (cm) about mean of GPS-Leveling minus model-derived geoid heights (number of points in brackets).
- For the topographic correction (Rapp 1997) the DTM2006.0 model (Pavlis et al. 2007) has been used.

<table>
<thead>
<tr>
<th>Region</th>
<th>EGM96</th>
<th>GGM02C/EGM96*</th>
<th>EIGEN-CG01C</th>
<th>EIGEN-GL04C</th>
<th>EIGEN-5C</th>
<th>EGM2008 (till d/o 360)</th>
<th>EGM2008 (till d/o 2190)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe (1234)</td>
<td>48</td>
<td>32</td>
<td>37</td>
<td>34</td>
<td>30</td>
<td>27</td>
<td>21</td>
</tr>
<tr>
<td>Germany (675)</td>
<td>29</td>
<td>17</td>
<td>22</td>
<td>18</td>
<td>15</td>
<td>14</td>
<td>4</td>
</tr>
<tr>
<td>Canada (1930)</td>
<td>36</td>
<td>26</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>23</td>
<td>13</td>
</tr>
<tr>
<td>USA (6169)</td>
<td>38</td>
<td>33</td>
<td>35</td>
<td>34</td>
<td>34</td>
<td>32</td>
<td>25</td>
</tr>
<tr>
<td>Australia (201)</td>
<td>30</td>
<td>25</td>
<td>26</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>22</td>
</tr>
</tbody>
</table>

* GGM02C up to d/o 200; EGM96 degrees > 200

EGM2008 fits best for the most data sets.

Used GPS/Leveling data sets:
- **USA**: Milbert, 1998
- **Canada**: M. Véronneau, personal communication 2003, Natural Resources Canada
- **Europe/Germany**: Ihde, personal communication 2008
- **Australia**: G. Johnston, Geoscience Australia and W. Featherstone, Curtin University of Technology, personal communication 2007
Quality improvement of EIGEN-5C: Reduction of stripes over continents - Europe/East Asia

EIGEN-GL04S1 (until d/o 150)

EIGEN-5S (until d/o 150)

EIGEN-5C (until d/o 360)

EIGEN-5C (until d/o 150)

Gravity anomaly

mGal

GFZ

Ocean Surface Topography Science Team meeting, 10-12 November 2008, Nice, France

Abstract No 032
Quality improvement of EIGEN-5C: Reduction of stripes over continents – North America

EIGEN-GL04S1 (until d/o 150)

EIGEN-5S (until d/o 150)

Gravity anomaly

EIGEN-5C (until d/o 150)

EIGEN-5C (until d/o 360)

mGal

Abstract No 032
Ocean Surface Topography Science Team meeting, 10-12 November 2008, Nice, France
Testing for meridional stripes: Residual ocean geoid

GGM02C – ( MSSH(GFZ) - DOT (ECCO) )

GGM02C/EGM96 vs. MSSH/ECCO
\[ \zeta, 0.5^\circ \times 0.5^\circ \]
wrms about mean / min / max = 0.213 / −2.088 / 3.046 meter
Testing for meridional stripes: Residual ocean geoid

EIGEN-GL04C – ( MSSH(GFZ) - DOT (ECCO) )

EIGEN–GL04C vs. MSSH/ECCO

$\zeta$, $0.5^\circ \times 0.5^\circ$

wrms about mean / min / max = 0.2277 / $-2.012$ / 2.706 meter
Testing for meridional stripes: Residual ocean geoid

EIGEN-5C – (MSSH(GFZ) - DOT (ECCO))

EIGEN–GL05C vs. MSSH/ECCO
ζ, 0.5° x 0.5°
wrms about mean / min / max = 0.206 / −1.951 / 2.419 meter
Testing for meridional stripes: Residual ocean geoid

EGM2008 (till d/o 360) – ( MSSH(GFZ) - DOT (ECCO) )
Summary

The new combined gravity field model **EIGEN-5C** has been obtained from the combination of GRACE & LAGEOS satellite data (= **EIGEN-5S** satellite-only model) and surface data.

**EIGEN-5C** shows the following improvements compared to previously released models:
- better orbit fits for GRACE and SLR satellites
- smoother spectral behaviour
- better reduction of meridional stripes
- better fit in GPS/Leveling comparisons

The **EIGEN-5C/S** coefficients are available for download at the **ICGEM** data base at GFZ Potsdam:

http://icgem.gfz-potsdam.de/ICGEM/ICGEM.html

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*ICGEM = The International Center of Global Earth Models at GFZ Potsdam is one of the six data centers of the International Gravity Field Service (IGFS) of the IAG*