Towards combined global monthly gravity field solutions

A. Jäggi¹, U. Meyer¹, M. Weigelt², T. van Dam², T. Mayer–Gürr³, J. Flury⁴, F. Flechtner⁵, C. Dahle⁵, J.–M. Lemoine⁶, S. Bruinsma⁶

¹Astronomical Institute, University of Bern, Switzerland

²Geophysics Laboratory, University of Luxembourg, Luxembourg

³Institute of Theoretical Geodesy and Satellite Geodesy, Technical University of Graz, Austria

⁴Institute of Geodesy, University of Hannover, Germany

⁵German Research Centre for Geosciences, Potsdam, Germany

⁶Groupe de Recherche de Geodesie Spatiale, Toulouse, France

EGU General Assembly, G4.2, 01 May 2014
Today, a variety of time–variable GRACE solutions are available from different groups:

- The solutions differ in terms of noise and (maybe) signal
- They may be based on different methodologies
- What can be done to make the best possible use of all these solutions?
- Is it possible to establish a meaningful combination?
Noise assessment

- weighted standard deviation (wSTD) over the oceans are computed to estimate the noise of the monthly solutions in a simple way

- an enlarged landmask is applied to compute the weighted STD in order to avoid leakage from continental regions with a strong hydrology signal
Noise assessment

wSTD over oceans (60)

AIUB–RL02: 9.8 mm  
GFZ–RL05a: 11.3 mm  
JPL–RL05 (90): 11.9 mm  
ITG2010 (trunc. 90): 4.2 mm  
ITSG2014 (90): 5.3 mm  
DMT–1 (trunc. 90): 0.7 mm

wSTD over oceans (90)

AIUB–RL02 (90): 1.5 mm  
GFZ–RL05a (90): 1.8 mm  
CSR–RL05: 1.3 mm  
Tongji: 1.3 mm  
GRGS–RL02 (50): 0.8 mm  
GRGS–RL03p: 3.2 mm

Solutions cannot be combined "just like that" due to different solution strategies.
Noise assessment

Sensitivity to ionosphere?
Why is there a different behavior for different solutions, e.g. for CSR?
Averaged monthly solutions
(input solutions based on similar strategies)

wSTD over oceans (60)

- AIUB–RL02 (60): 1.5 mm
- GFZ–RL05a (60): 1.8 mm
- CSR–RL05: 1.3 mm
- Tongji–RL01: 1.3 mm
- GRGS–RL03p: 3.2 mm
- Mean of 3: 1.2 mm
- Mean of 4: 1.1 mm
- Mean of 5: 1.0 mm

AIUB new (90): 9.8 mm
GFZ–RL05a (90): 11.3 mm
JPL–RL05 (90): 11.9 mm
ITSG–2014 (90): 5.3 mm
Mean of 3: 7.8 mm
Mean of 4: 6.4 mm
Mean of 5: 6.0 mm

ITSG makes use of empirical covariances to model the noise behavior.
Signal (hydrology in South America)

300km Gauss smoothed

Water [m]

Signal (ice mass change in Greenland)

300km Gauss smoothed

Only solutions based on comparable processing strategies should be used for a meaningful combination – regularizations may lead to different trends.

- AIUB-RL02: $-23 \pm 1.3$ mm/y
- JPL-RL05: $-20 \pm 2.3$ mm/y
- CSR-RL05: $-20 \pm 0.7$ mm/y
- CSR: $-20 \pm 0.7$ mm/y
- GFZ: $-31 \pm 1.1$ mm/y
- GFZa: $-24 \pm 1.4$ mm/y
- ITG: $-28 \pm 1.6$ mm/y
- ITSG: $-24 \pm 0.8$ mm/y
- GRGS: $-36 \pm 0.4$ mm/y
- GRGS-RL05p: $-20 \pm 1.3$ mm/y
- GRGS: $-20 \pm 1.3$ mm/y
- DMT: $-34 \pm 1.3$ mm/y

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Averaged monthly solutions
(input solutions based on similar strategies)

**max. degree 60**

<table>
<thead>
<tr>
<th>Solution</th>
<th>Rate (mm/y)</th>
</tr>
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<tbody>
<tr>
<td>AIUB–RL02 (60)</td>
<td>$-20 \pm 0.9$</td>
</tr>
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<td>$-20 \pm 1.2$</td>
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<td>CSR–RL05</td>
<td>$-20 \pm 0.7$</td>
</tr>
<tr>
<td>TON–RL01</td>
<td>$-22 \pm 0.9$</td>
</tr>
<tr>
<td>GRGS–RL03</td>
<td>$-20 \pm 1.3$</td>
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<td>Mean of 3</td>
<td>$-20 \pm 1.2$</td>
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<tr>
<td>Mean of 4</td>
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<td>Mean of 5</td>
<td>$-20 \pm 1.0$</td>
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**max. degree 90**

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<td>JPL–RL05(90)</td>
<td>$-20 \pm 2.3$</td>
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<tr>
<td>ITSG–2014 (90)</td>
<td>$-24 \pm 0.8$</td>
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<tr>
<td>Mean of 3</td>
<td>$-19 \pm 2.0$</td>
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<td>Mean of 4</td>
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Averaged monthly solutions
(input solutions based on similar strategies)

max. degree 60

AIUB–RL02(60): $-20 \pm 1.9$ mm/y
GFZ–RL05a (60): $-22 \pm 1.7$ mm/y
CSR–RL05: $-19 \pm 1.2$ mm/y
TON–RL01: $-24 \pm 1.2$ mm/y
GRGS–RL03: $-17 \pm 1.9$ mm/y
Mean of 3: $-20 \pm 1.2$ mm/y
Mean of 4: $-20 \pm 1.1$ mm/y
Mean of 5: $-20 \pm 1.0$ mm/y

max. degree 90

AIUB–RL02: $-20 \pm 1.9$ mm/y
GFZ–RL05a: $-25 \pm 2.2$ mm/y
JPL–RL05(90): $-19 \pm 3.0$ mm/y
ITSG–2014 (90): $-22 \pm 1.2$ mm/y
Mean of 3: $-19 \pm 2.0$ mm/y
Mean of 4: $-19 \pm 1.6$ mm/y

Same time span: 2004–2010
Averaged monthly solutions
(input solutions based on similar strategies)

**max. degree 60**

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<tr>
<td>GRGS–RL03</td>
<td>$-18 \pm 2.5$ mm/y</td>
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Same time span: 2004–2009
Averaged monthly solutions
(input solutions based on similar strategies)

max. degree 60

AIUB–RL02 (60): $-18 \pm 2.1\ mm/\ y$
GFZ–RL05a (60): $-21 \pm 2.7\ mm/\ y$
CSR–RL05: $-17 \pm 2.1\ mm/\ y$
TON–RL01: $-22 \pm 1.7\ mm/\ y$
GRGS–RL03: $-18 \pm 3.2\ mm/\ y$
Mean of 3: $-20 \pm 1.2\ mm/\ y$
Mean of 4: $-20 \pm 1.1\ mm/\ y$
Mean of 5: $-20 \pm 1.0\ mm/\ y$

Same time span: 2005–2009

max. degree 90

AIUB–RL02: $-18 \pm 2.8\ mm/\ y$
GFZ–RL05a: $-22 \pm 3.3\ mm/\ y$
JPL–RL05(90): $-22 \pm 3.6\ mm/\ y$
ITSG–2014 (90): $-19 \pm 2.0\ mm/\ y$
Mean of 3: $-19 \pm 2.0\ mm/\ y$
Mean of 4: $-19 \pm 1.6\ mm/\ y$
Coefficient-wise significance of annual variations

F-test: annual AIUB–RL02

F-test: annual GFZ–RL05a

F-test: annual JPL–RL05

F-test: annual ITSG–2014
Coefficient–wise significance of trends

F–test: trend AIUB(new)

F–test: trend GFZ–RL05a

F–test: trend JPL–RL05

F–test: trend ITSG–2014

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RMS of monthly differences per coefficient

**JPL–RL05 – AIUB–RL02**

**GFZ–RL05a – AIUB–RL02**

**JPL–RL05 – GFZ–RL05a**

**ITSG–2014 – AIUB–RL02**
Monthly relative weights (example 03/2008)

Contribution per order

Percent: $100\% \times \frac{w_i}{w_1 + w_2 + w_3}$

Weight matrix: $1/RMS^2$ per order

Mean:
- AIUB: 25 %
- GFZ: 20 %
- CSR: 24 %
- TON: 27 %
- GRGS: 4 %
Monthly relative weights 90 (example 03/2008)

Contribution per order

Percent: $100\% \times \frac{w_i}{(w_1 + w_2 + w_3)}$

Weight matrix: $1 / \text{RMS}^2$ per order

Mean:
- AIUB: 30 %
- GFZ: 22 %
- JPL: 14 %
- ITSG: 34 %
Monthly relative weights 90

AIUB–RL02
Monthly relative weights 90
Monthly relative weights 90

ITSG–2014

percent

order

2005 2006 2007 2008 2009

percent

2004 2005 2006 2007 2008 2009 2010

Astronomical Institute University of Bern

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Summary in view of GRACE–FO

- A service should be established consisting of:
  - A larger number of Analysis Centers (ACs) providing time-variable gravity field solutions on a regular basis
  - Analysis Center Coordinator (ACC)

- Comparable processing strategies are mandatory to ensure meaningful results of the ACC work:
  - Comparison of the AC solutions (gravity field solutions, orbits, residuals), identification of problematic solutions
  - Pairwise comparison of solutions to derive approximate empirical weights for the individual ACs
  - Combination of all AC gravity fields, either by:
    - Calculating a weighted average of the gravity field parameters based on the previously derived weights
    - Combining the solutions based on normal equations generated by the individual ACs