Progresses in time-variable gravity modelling
Results from the CNES/GRGS reprocessing

R. Biancale, J.-M. Lemoine, S. Bruinsma, S. Bourgogne\textsuperscript{1}, S. Gratton, F. Perosanz, J.-C. Marty, G. Balmino, N. Vales, S. Melachroinos\textsuperscript{2}

CNES / GRGS Team of Space Geodesy, Toulouse, France

\textsuperscript{1}) Noveltis, Ramonville, France
\textsuperscript{2}) CNES post-doc at LEGOS, Toulouse, France

0STST 2008, POD session, November 11, 2008, Nice, France
STANDARDS

Reprocessing, new features:

• A priori gravity field: EIGEN-GL04C to degree and order 160
• Desaï model for the oceanic pole tide (up to degree 100)
• The number of solvable oceanic tide parameters has been increased to maximum degree & order 30 according to a priori sensitivity analysis
• KBR and GPS data editing have been improved (more valid days / 10-day period)
• The solutions are still computed every 10 days, but are based solely on those 10 days.

This reprocessing will lead to…

➢ a new series of 10-day solutions ;
➢ a new “mean” (i.e. static+drifts+annual&semi-annual terms) gravity field model: EIGEN-6p (preliminary for the moment).
Should a time-variable part be solved-for?

- Not solving for low-degree (< degree 30 to 50) terms has a noticeable impact on static solution at higher degrees (between degrees 60 and 100).

Comparison of solutions

WITH and WITHOUT solving for time-variable terms until dg 30

Equivalent Water Height and Error (m)

- Difference of solutions
- Sigma of solutions

Spherical Harmonic Degree
1- Should a time-variable part be solved-for?

- Same applies, to a lesser extent, to oceanic tide coefficients.
2- Up to which degree should a time-variable part be solved-for?

- Current configuration: degree 30, but there are indications that 50 would be preferable.
2- Up to which degree should a time-variable part be solved-for?

- Image of the drifts at degree 30.

Annual trend in Equivalent Water Height from EIGEN-6p
between mid-2002 and end-2007
dergee 1 to 30
(unit: m/y)
(mean: -0.0000 / st.dev: 0.0135 / min: -0.1742 / max: 0.0631)
2- Up to which degree should a time-variable part be solved-for?

- Image of the drifts at degree 50 (from regression on 10-day solutions).

Trend from GRACE over 5 years (mid-2002 to mid-2007) in Equivalent Water Height.

unit: m/y; spherical harmonic degrees 2 to 50
GRACE solutions error for Trend: 0.9 cm/y RMS
(rms: 0.0149 / moy: 0.0000 / min: -0.1794 / max: 0.0717)
1- Post-glacial rebound
2- Glacier melting
3- Hydrological trends
4- Sumatra earthquake
2- Up to which degree should a time-variable part be solved-for?

- Image of the annual terms at degree 50 (from regression on 10-day solutions).
2- Up to which degree should a time-variable part be solved-for?

- Image of the semi-annual terms at degree 50 (from regression on 10-day solutions).
2- Up to which degree should a time-variable part be solved-for?

- Image of the semi-annual terms at degree 50 (different scale).

Semi-Annual amplitude from GRACE over 5 years
(mid-2002 to mid-2007) in Equivalent Water Height.
unit: m; spherical harmonic degrees 2 to 50
GRACE solutions error for Semi-Annual amplitude: 1.1 cm RMS
(rms: 0.0093 / moy: 0.0130 / min: 0.0000 / max: 0.1211)
3- Should we use « secular trends » or « broken line »?

- In some cases, a “broken line” seems more appropriate (e.g. Greenland)… or C(2,0);

BUT…

- More parameters → more noise;
- More difficult to implement for users;
- Problem of predictability (extrapolation);
- If great accuracy is needed, then the time series solution can be used!
4- Should degree 1 be solved-for?

- It implies the inclusion of Lageos data in the solution. (Same remark applies for degree 2)
- The values obtained in the framework of EIGEN-6 are very small:

<table>
<thead>
<tr>
<th></th>
<th>C(1,0)</th>
<th>C(1,1)</th>
<th>S(1,1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>bias</td>
<td>1 mm</td>
<td>0 mm</td>
<td>0 mm</td>
</tr>
<tr>
<td>annual drift</td>
<td>0.6 mm/y</td>
<td>0 mm/y</td>
<td>0 mm/y</td>
</tr>
<tr>
<td>annual term</td>
<td>0.2 mm</td>
<td>1 mm</td>
<td>1.8 mm</td>
</tr>
<tr>
<td>semi-annual term</td>
<td>0.8 mm</td>
<td>0 mm</td>
<td>0.2 mm</td>
</tr>
</tbody>
</table>
5- Should a « combined » field be used?

- Why not, if the merging of space data with surface data is well done.

Comparison EIGEN-6p / ITG-GRACE03S / EGM2008
6- How to deal with “Sumatra-type” events?

SUMMARY

- Should a time-variable part be solved-for?
  YES

- Up to which degree should a time-variable part be solved-for?
  Degree 50 for drifts and annual terms, 30 to 50 for semi-annual terms.

- Should we use « secular trends » or « broken line »?
  Rather « secular trends »; for more precise solutions it is possible to use time series solutions.

- Should degree 1 be solved-for?
  YES, but it depends very much on the reference frame (station coordinates) used.

- Should a « combined » field be used?
  Why not, but the connection between space and surface data must be carefully weighted.

- How to deal with “Sumatra-type” events?
  For major events, like the Sumatra earthquake, introduce jumps in the gravity field.
<table>
<thead>
<tr>
<th></th>
<th>C(3,1)</th>
<th>S(3,1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EIGEN-GL04S</td>
<td>0.15474352083236E-10</td>
<td>-0.32582549345132E-10</td>
</tr>
<tr>
<td>EIGEN-6p</td>
<td>0.25057325754129E-11</td>
<td>0.19656936266564E-10</td>
</tr>
</tbody>
</table>
## Orbit tests

<table>
<thead>
<tr>
<th>Satellite</th>
<th>max. degree used</th>
<th>GGM02C</th>
<th>GGM03S</th>
<th>JEM1-RL03B</th>
<th>EIGEN-GL04C</th>
<th>EIGEN-5S</th>
<th>EIGEN-5C</th>
<th>ITG-GRACE03S</th>
<th>EGM2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHAMP</td>
<td>120 x 120</td>
<td>5.32</td>
<td>5.45</td>
<td>5.35</td>
<td>5.44</td>
<td>5.55</td>
<td>5.51</td>
<td>5.38</td>
<td>5.51</td>
</tr>
<tr>
<td></td>
<td>150 x 150</td>
<td>5.19</td>
<td>5.44</td>
<td>--</td>
<td>5.41</td>
<td>5.56</td>
<td>5.49</td>
<td>5.30</td>
<td>5.46</td>
</tr>
<tr>
<td>GRACE</td>
<td>120 x 120</td>
<td>5.50</td>
<td>5.28</td>
<td>5.55</td>
<td>5.25</td>
<td>5.17</td>
<td>5.15</td>
<td>5.39</td>
<td>5.46</td>
</tr>
<tr>
<td></td>
<td>150 x 150</td>
<td>5.54</td>
<td>5.27</td>
<td>--</td>
<td>5.24</td>
<td>5.19</td>
<td>5.14</td>
<td>5.38</td>
<td>5.43</td>
</tr>
</tbody>
</table>

Table 2: SLR residuals (cm) after an orbit determination based on GPS-SST and accelerometer data (CHAMP, GRACE) and K-Band Range-Rate data (GRACE). The SLR data were not included for the orbit adjustment. The best orbit fits are marked red.
TREND from July 2002 through February 2008

Trend from GRACE over 5 years (mid-2002 to mid-2007)
in Equivalent Water Height.
unit: m/y; spherical harmonic degrees 2 to 50
GRACE solutions error for Trend: 0.9 cm/y RMS
(rms: 0.0149 / moy: 0.0000 / min: -0.1794 / max: 0.0717)
GLOBAL MAPS IN EWH

ANNUAL SIGNAL

Maximum amplitude 52 cm EWH
GLOBAL MAPS IN EWH

SEMI-ANNUAL SIGNAL

Maximum amplitude 12 cm EWH

Semi-Annual amplitude from GRACE over 5 years
(mid-2002 to mid-2007) in Equivalent Water Height.
unit : m; spherical harmonic degrees 2 to 50
GRACE solutions error for Annual amplitude: 1.1 cm RMS
(rms : 0.0093 / moy : 0.0130 / min : 0.0000 / max : 0.1211)
GLOBAL MAPS IN EWH

SEMI-ANNUAL SIGNAL (different scale)

Maximum amplitude 12 cm EWH
CONCLUSIONS

• The reprocessing of all GRACE data (from 2002 till end of 2007) has been completed by CNES/GRGS with homogeneous standards.

• The new time series will be provided every 10 days (as the current one) but will only be based on 10 days of data.

• The stabilization constraint used allows the recovery of the solutions with very limited striations and with no attenuation until degree 30 (resolution 666 km). Above this limit, and until degree 50, there is a gradual decrease in the power of the solutions, which means that the signal will be damped for resolutions below 666 km.

• For the study of mass balance over glacial regions, particularly Antarctica, two points need a special attention:
  
  ➢ the uncertainties of the PGR models, which are still very large;
  
  ➢ a careful consideration of the degrees 1 and 2 of the gravity field, implying the inclusion of SLR measurements on other geodetic satellites in the solutions.

• As a consequence of this reprocessing, a new mean field including 6 years of data has been derived up to degree 160. It contains drift, annual and semi-annual periodic terms up to degree 30.

• The new 10-day series will be available on the BGI web site in the coming months.
C(2,0) time series

(difference to -4.84165198e-3)

EXTRAPOLATION of C(2,0) time evolution

year

Delta C(2,0)