Validation of GRACE time-variable gravity field by ICESat, GPS, WGHM and altimetry satellites

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Outline of talk

- GRACE data solutions (CSR5, GFZ4, GFZ5a, RBF)
- Greenland/Continental GPS uplift rates (GNET, CODE)
- Ice mass balances (ICESAT)
- Sea level budgeting from (Ant-) Arctic
- Hydro-basin comparisons (WGHM)
- Kalman Filtering for daily updates
- Hydraulic inundation volumes (in-situ)
- Altimetry Satellites (RMS-fits, ARC/overlap)
Greenland GPS comparison

Spread of ice mass loss into northwest Greenland observed by GRACE and GPS
Shfaqat Abbas Khan, John Wahr, Michael Bevis, Isabella Velicogna and Eric Kendrick (2010)

- GNET GPS vertical displacements (2002-2012)
- GRACE gravity fields (RL04, RL05a, RBF, CSR05)
  - Add degree C_10, C_11, S_11 (CM->CF)
  - Replace C_20 (SLR), being poorly observed by GRACE
  - Add atmospherical loading (GAC)
  - Prepare GIA: ICE_5G_v1.3 (Peltier 2012), -> Sph. Harmonics, CF removed
  - Remove GIA from GRACE temporal coefficients
  - Compute crustal uplift signal in GNET sites (transfers with elastic load LOVE numbers k_n, h_n)
  - Restore full ICE_5G uplift rates (part of GPS displacements)
  - Correlate with GPS time series, show average correlation over all stations
GPS sites correlation: Greenland

<table>
<thead>
<tr>
<th>Model</th>
<th>Correlation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RL04</td>
<td>35.8%</td>
</tr>
<tr>
<td>RL05</td>
<td>36.7%</td>
</tr>
<tr>
<td>RBF</td>
<td>36.7%</td>
</tr>
<tr>
<td>CSR05</td>
<td>36.1%</td>
</tr>
</tbody>
</table>

IAG/IUGG, G03 Variations of the Gravity Field, Praha, Czech Republic, June 24, 2015
GPS station network 2002-2012

<table>
<thead>
<tr>
<th>Model</th>
<th>Percentage</th>
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<td>RBF</td>
<td>39.4%</td>
</tr>
<tr>
<td>CSR05</td>
<td>40.5%</td>
</tr>
</tbody>
</table>

ICE Sat and GRACE mass change

Mass balances

Greenland

$-230.4 \pm 18.8 \text{ Gt/a} (4.2 / 18.3)$

Antarctica

$-147.7 \pm 30.1 \text{ Gt/a} (7.3 / 29.2)$
Mass balances

Greenland

CSR $-230.7 \pm 23.6$ Gt/a (15.2 / 18.1)
GFZ $-239.0 \pm 23.7$ Gt/a (15.2 / 18.1)
RBF $-230.4 \pm 18.8$ Gt/a (4.2 / 18.3)

Antarctica

CSR $-110.8 \pm 30.3$ Gt/a (9.2 / 28.9)
GFZ $-124.1 \pm 30.2$ Gt/a (8.8 / 28.9)
RBF $-147.7 \pm 30.1$ Gt/a (7.3 / 29.2)
Uplift rates / sea level change

- Trend estimates for 2003.0-2013.12 \( \text{GFZRL05a} \)
- Iterative leakage correction \( \rightarrow \) relocation of mass-signal on land
- Load induced crustal uplift for Greenland \( \rightarrow \) max \( +8.5\text{mm/a} \)
- Load induced crustal uplift for Antarctica \( \rightarrow \) max \( +10.3\text{mm/a} \)
- Iterative computation of RSL
Crustal deformation
relative sea level trends

Relative sea level change: min -11.3 max 2.9 mm/a
Eustatic (w/o thermal expansion) $\Rightarrow +0.66 + 0.34 = +1.00\text{mm/a}$
Major hydrological basins (WGHM) 2002/4-2013/6

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<tr>
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<th>Correspondence %</th>
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<tr>
<td>CSR05</td>
<td>52.6%</td>
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</table>
Data Input (daily arcs)

KBR Observations

Auto-correl., Emp. Cov Functions

Least Squares Prediction

System update Kalman Gain

Background Modeling

Monthly/Daily Cross/Covariance

Deterministic constraints

Stochastic constraints

AOD1B 6h glo

EIGEN6c static

Tides

WaterGap Mod + AOD1B

External Data

Daily Output
Noise reduction

Annual- and Semiannual Signal (RBF)

Annual- and Semiannual Signal (RL05)
Comparison: GRACE vs. “In situ Hydrology”

Lower Mekong

Comparing mass changes from GRACE with hydraulic simulations of the large scale annual inundation volume (red points: calibration).

• Rainfall periods 2008-2011: monthly and daily solutions compared to specific hydraulic modeling of inundation Volumes in the lower Mekong.

• The daily Kalman solutions follow the inundations from the hydraulic modeling better than monthly means and show the potential for hydrological monitoring. WGHM for general comparison.

• Phase lags occur after loss of data (availability).
Global assessment: WGHM

RMS differences:
\[ \text{rms}(\text{RBF-WGHM}) - \text{rms}(\text{RL05a-WGHM}) \]

Correlations:
\[ (\text{RL05a,WGHM}) - (\text{RBF,WGHM}) \]

Min -137.8/ Max 110.1 / Std. 16.9 [mm]
Altimetry Satellite orbits

DORIS RMS

DORIS RMS fits, Jason-1 [cm/s]

DORIS RMS fits, Jason-2 [cm/s]

Time (year)

Envisat EIGEN-6S2
Envisat RBFv04

Jason-1 EIGEN-6S2
Jason-1 RBFv04

Jason-2 EIGEN-6S2
Jason-2 RBFv04
Altimetry Satellite orbits
SLR RMS

SLR RMS fits, Envisat [cm]

Envisat EIGEN-6S2
Envisat RBFv04

Time (year)

SLR RMS fits, Jason-1 [cm]

SLR RMS fits, Jason-2 [cm]

Time (year)
Altimetry Satellite orbits
Radial Arc overlap

Time (year)

Radial arc overlap, Jason-1 [m]

Radial arc overlap, Jason-2 [m]

Envisat EIGEN-6S2
Envisat RBFv04

Jason-1 EIGEN-6S2
Jason-1 RBFv04

Jason-2 EIGEN-6S2
Jason-2 RBFv04
## Satellite Altimetry Orbits

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Orbital Altitude [km]</th>
<th>Model/ Solution</th>
<th>SLR RMS fits [cm]</th>
<th>DORIS RMS fits [cm/s]</th>
<th>Radial arc overlap [cm]</th>
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<tbody>
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<tr>
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<td>RBF</td>
<td>1.63</td>
<td>.0350</td>
<td>.83</td>
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</table>

The mean values of SLR and DORIS RMS fits and radial arc overlap for **Envisat (2002-2012)**, **Jason-1 (2002-2012)** and **Jason-2 (2008-2014)** obtained using EIGEN-6S2_extended_v2 model and RBFv04 solutions. The orbits were computed at 7-day arcs for Envisat and 12-day arcs for Jason-1 and Jason-2.
Summary and Outlook

- GNET and CODE GPS uplift rates confirm temporal loading
- Sea level budget/Ice mass balance (ICESAT, soon: CryoSat2)
- Hydro-basin comparisons (WGHM) for basin size dependent analysis
- Hydraulic inundation volumes to reveal GRACE temporal sensitivity
- Satellite Altimetry orbit for quality assessment of daily/weekly arcs
- Switch from Post processing to Near Real Time...
Thanks for your attention!