Pushing the limits of gravity field recovery from high-low satellite-to-satellite tracking – a combination of 10 years of data of the satellite pseudo-constellation CHAMP, GRACE and GOCE

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Recall EGU 2013 - van Dam et al. (2013)

• Long wavelength features can be recovered from CHAMP/hl-SST, e.g. the trend in Greenland

• Strong spatial error pattern, e.g. in Africa and Asia
COMBINING CHAMP, GRACE A/B AND GOCE
Data availability for period 2003 to 2012
Data processing

GPS positions for CHAMP:
- Prange (2010)
- 10 s sampling
- empirical absolute antenna phase center model

GPS positions for GRACE A/B and GOCE:
- Zehentner et al. (2014) (subsequent talk)
- 10 s sampling
- direct use of code and phase observations
- empirical absolute antenna phase center model

Approach:
- acceleration approach
- no accelerometer data used
- no regularization and no *a priori* model / information

Result: time series of monthly gravity field solutions for each satellite
REFINED KALMAN-FILTER APPROACH
Kalman-Filter

- formerly using the approach of Davis et al. (2012)
- changing to Kurtenbach et al. (2009)
- advantage: the process noise is implicitly defined

processing scheme:

Time series

Least squares: trend + mean annual signal

Prediction model (Filter Design)

Kalman filter

Filtered time series
Kalman-Filter: prediction model

- Kalman-Filter: concept of least-squares prediction
  - assuming a stochastic process
  - description by auto- and cross-correlation functions
  \[ \rightarrow \] prediction model
- in Kurtenbach et al. (2009) correlation functions empirically derived from hydrological models
- Here: no usage of a priori information
- Instead: filter design can be converted to a correlation function
- Filter: only variations around the annual signal
Kalman-Filter: prediction model

Power spectrum of the process noise

- Normalized power
- Cycles per year
RESULTS
Degree RMS

![Graph showing degree RMS with different datasets: EGM2008, CHAMP v1, CHAMP v2, CHAMP v2 Kalman, GRACE CSR Rel05, CHAMP+GRACE+GOCE+Kalman. The graph plots degree l on the x-axis and the RMS value on the y-axis in units less. The datasets are represented by different colors and line styles.](image-url)
Time series of coefficients
Spatial pattern

**CHAMP Kalman**

- Trend
- Amplitude
- Phase

**Combined Kalman**

- Trend
- Amplitude
- Phase

- eq. water height [cm/year]
- eq. water height [cm]
- phase [month of the year]
Comparison with hydro-meteorological data

- Comparison with the difference of vertical integrated moisture flux divergences (ERA-INTERIM) and river discharge (GPCC)
Mass trend estimates

CHAMP-only

Combined

GRACE
## Mass trend estimates

<table>
<thead>
<tr>
<th>Area</th>
<th>Filter radius</th>
<th>GRACE GT/yr</th>
<th>CHAMP-only GT/yr</th>
<th>Δ to GRACE in %</th>
<th>Combined GT/yr</th>
<th>Δ to GRACE in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenland</td>
<td>1000 km</td>
<td>-239 ± 9</td>
<td>-261 ± 8</td>
<td>7</td>
<td>-208 ± 8</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>750 km</td>
<td>-238 ± 7</td>
<td>-255 ± 7</td>
<td>9</td>
<td>-218 ± 7</td>
<td>8</td>
</tr>
<tr>
<td>Amazon</td>
<td>1000 km</td>
<td>90 ± 18</td>
<td>120 ± 9</td>
<td>33</td>
<td>95 ± 11</td>
<td>6</td>
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<tr>
<td></td>
<td>750 km</td>
<td>92 ± 17</td>
<td>128 ± 9</td>
<td>39</td>
<td>96 ± 10</td>
<td>4</td>
</tr>
<tr>
<td>Antarctica</td>
<td>1000 km</td>
<td>52 ± 16</td>
<td>250 ± 21</td>
<td>481</td>
<td>42 ± 20</td>
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</tr>
<tr>
<td></td>
<td>750 km</td>
<td>50 ± 14</td>
<td>247 ± 20</td>
<td>494</td>
<td>39 ± 19</td>
<td>22</td>
</tr>
</tbody>
</table>
GIA

Combined hl-SST

Maximum = 0.39 µGal/a

GRACE GFZ Rel05

Maximum = 0.44 µGal/a

Maximum = 0.47 µGal/a

Maximum = 0.73 µGal/a
Conclusion:

• Combination yields improved time-variable estimates from hl-SST

• Results agree well with GRACE, hydro-meteorological data and loading from GNSS (not shown here).

• Spatial resolution improves from approximately degree 8 to 13.

• Mass estimates differ at most 22% to GRACE estimates.

• GIA estimates show first promising results but remain difficult.