Bridging the gap – linking GRACE and GRACE-Follow On by hISST and SLR

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Motivation

• Bridging the gap between GRACE and GRACE-FO
• Bridging the gaps of GRACE
• Cross-validating GRACE and GRACE Follow-On
• Combination of gravity fields from various sources for improved recovery
• Study multi-mission multi-satellite environments

courtesy Felix Landerer using JPL mascons – Watkins et al. 2015
h|SST data processing
Acceleration approach and background models

- Kinematic orbits from
  - Astronomical Institute, University Bern
  - Institute for Geodesy, Graz
  - Institute for Geodesy, Hannover
  - European Space Agency
totalling to 41 kinematic orbit products from 27 satellites.

- Accelerometer data used for CHAMP, GRACE and GOCE

- Acceleration approach and combination on the normal equation level using variance component estimation

- Background models
  - JPL Ephemeris DE421
  - Solid Earth tides (IERS Conventions)
  - Solid Earth pole tides (IERS Conventions)
  - Ocean tides (FES2014b)
  - Ocean pole tides (IERS Conventions)
  - Atmospheric tides (AOD1B RL06)
  - Relativistic corrections (IERS conventions)
  - AOD1B dealiasing product RL06
A new differentiator

- Differentiation amplifies noise.
- Low-pass filtering properties of differentiators are used to suppress noise.
- Test showed that for sampling >30s a time-shifted 30s filter is optimal.
Impact on the estimated noise spectrum: here for GRACE A

30 sec time-shifted

Maximum Flat
Key elements of the data processing
Combination with satellite laser ranging

- **9 satellites**
  - Lageos 1
  - Lageos 2
  - LARES
  - Starlette
  - Stella
  - Larets
  - AJISEI
  - Beacon-C
  - Blits

- **Combined estimation:**
  - gravity parameters till degree 10,
  - station coordinates,
  - Earth rotation parameter,
  - geocenter,
  - range biases

- **Combination at the normal equation level using variance component estimation**
Temporal filtering

Kalman filter:
- continuous Wiener process acceleration (CWPA) model
- accelerations as white noise model
Difference degree RMS w.r.t. GOCC05s

Temporal filtering

- ITSG2018s
- ITSG2018 degree 60
- CSR GRACE Rel06
- CSR GRACE-FO Rel06
- hiSST-only V2017
- hiSST-only V2018
- hiSST-only V2019
- hiSST + SLR V2019
- hiSST + SLR Kalman V2019
Spatial RMS over ocean areas

Gaussian filter 750 km
Temporal signal evaluation
Trend

hISSST+SLR Kalman 2019
Trend in eq. water height [cm/year]

GRACE CSR Rel06
Trend in eq. water height [cm/year]
Annual signal amplitude

hISST+SLR Kalman 2019
Mean annual amplitude in eq. water height [cm]

GRACE CSR Rel06
Mean annual amplitude in eq. water height [cm]

Gaussian filter 750 km
Bridging the gap
Filtering + Combination

Hypothesis: combine various data sets within the same Kalman filter environment

GRACE
- Monthly SH coefficients

GRACE Follow-On
- Monthly SH coefficients

hISST+SLR
- Monthly SH coefficients

Least squares adjustment
- Trend + Annual cycle
  - Semi-annual cycle

Kalman filter
- residual
- filtered signal

Kalman filter:
- continuous Wiener process acceleration (CWPA) model
- accelerations as white noise model

Filtered SH coefficients
Coefficient-wise combination $S_{22}$

Strong weight on hISST+SLR solution due to low variability
Coefficient-wise combination $C_{70}$

**Introduction of systematic errors in the hISST+SLR solution**
Spatial RMS over ocean areas

Combined solution is oversmoothed (loss of signal) due to Kalman filter properties (=low-pass filter)
Conclusion
Conclusions

• Mutual benefit by combining HLSST and SLR:
  • SLR improves (dominates) the degree-2 coefficients
  • HLSST provides the higher spatial resolution.
• HLSST + SLR solutions may be best suited for detecting inter-annual and annual variations.
• Short-term variations are not observable due to the limited spatial resolution and the higher noise level of the solutions.
• Combination of GRACE, GRACE Follow-On and HLSST+SLR in the Kalman-filter environment is inferior in periods where GRACE and GRACE Follow-On data is available caused by an oversmoothing due to the Kalman-Filter properties.