Advanced processing strategies for an improved GFZ GRACE/GRACE-FO Level-2 data release

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Introduction

GFZ, as part of the GRACE/GRACE-FO Science Data System (SDS), is one of the official Level-2 processing centers routinely providing monthly gravity models. These models are used by a wide variety of geoscientists to infer mass changes mainly at the Earth's surface. While the current release 6 (RL06) is still operationally processed, plans and internal tests for a reprocessed GFZ RL07 time series are already in progress. In this context, recent developments have been made within the Research Unit (RU) NEROGRAV (New Refined Observations of Climate Change from Spaceborne Gravity Missions), funded by the German Research Foundation DFG. Aiming at an increased resolution, accuracy, and long-term consistency of mass transport series from satellite gravimetry, two of the individual projects within the RU closely interact on optimized space-time parameterization (reducing non-tidal temporal aliasing error effects) and stochastic modeling regarding instrument data (accelerometer and inter-satellite ranging observations) as well as background models (e.g. by the utilization of covariance information for ocean tides). Furthermore, a new version RL06.1 of GFZ's current GRACE-FO release using a new SDS ACC transplant product is presented.

Stochastic modeling of instrument data

Main idea

- Analysis of in-orbit performance of GRACE/GRACE-FO accelerometers (ACC) and inter-satellite ranging instruments (MWI and LRI)
- Derivation of realistic noise models for ACC, MWI and LRI
- Stochastic modeling of range-rate data within GFZ Level-2 processing based on these noise models

Method

- ACC: residual analyses of transplanted ACC observations for GRACE test years 2007 and 2014
- MWI/LRI: analyses of postfit residuals of GFZ GRACE/GRACE-FO RL06 solutions; comparison with pre-launch specifications
- A priori stochastic models for range-rate observations regarding combined ACC+MWI/LRI noise

Results

- ACC: worse performance (factor of 3) in 2014 compared to 2007 (Fig. 1, right panel)
- MWI: lower noise (factor of 2) for GRACE-FO compared to GRACE (Fig. 1, left panel)
- More realistic formal error behavior when applying the a priori stochastic models (Fig. 2)
- Same gravity field quality level (Fig. 2, left panels)
- Stochastic modeling reduces need for empirical parameters

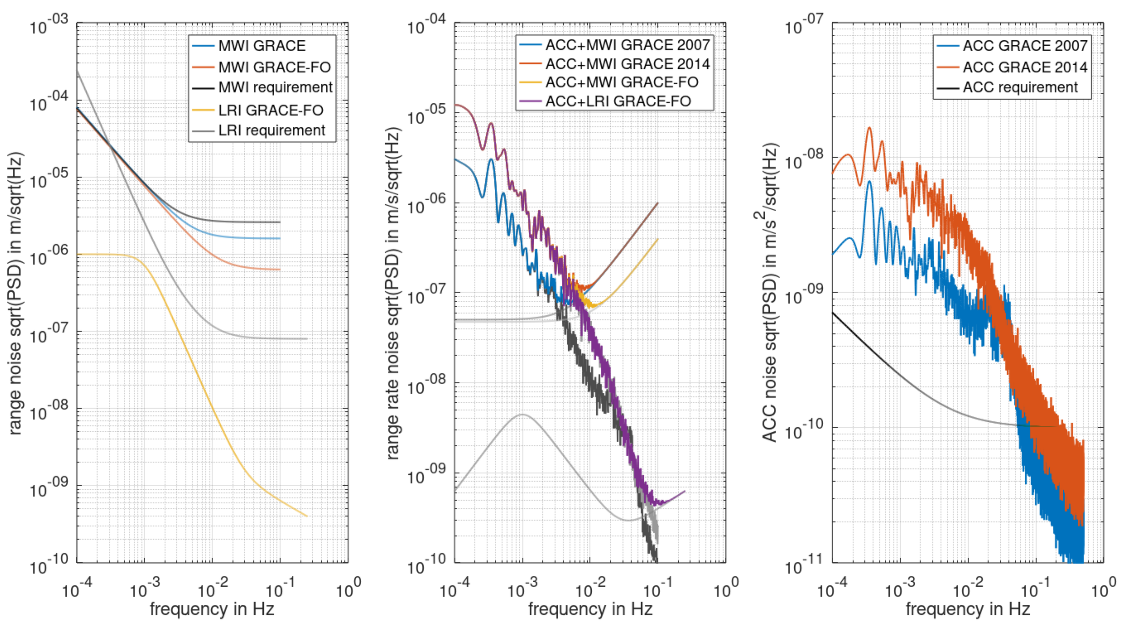

Fig. 1: Noise models in terms of amplitude spectral densities (ASDs) of the key GRACE/GRACE-FO instruments; left: GRACE MWI (blue), GRACE-FO MWI (red), GRACE-FO LRI noise models and requirements in terms of range ASDs in m/sqrt(Hz); right: GRACE ACC noise models for 2007 (blue) and 2014 (red) with requirements in terms of acceleration ASDs in m/s²/sqrt(Hz); center: combined GRACE ACC+MWI/LRI noise models in terms of range-rate ASDs in m/s/sqrt(Hz).

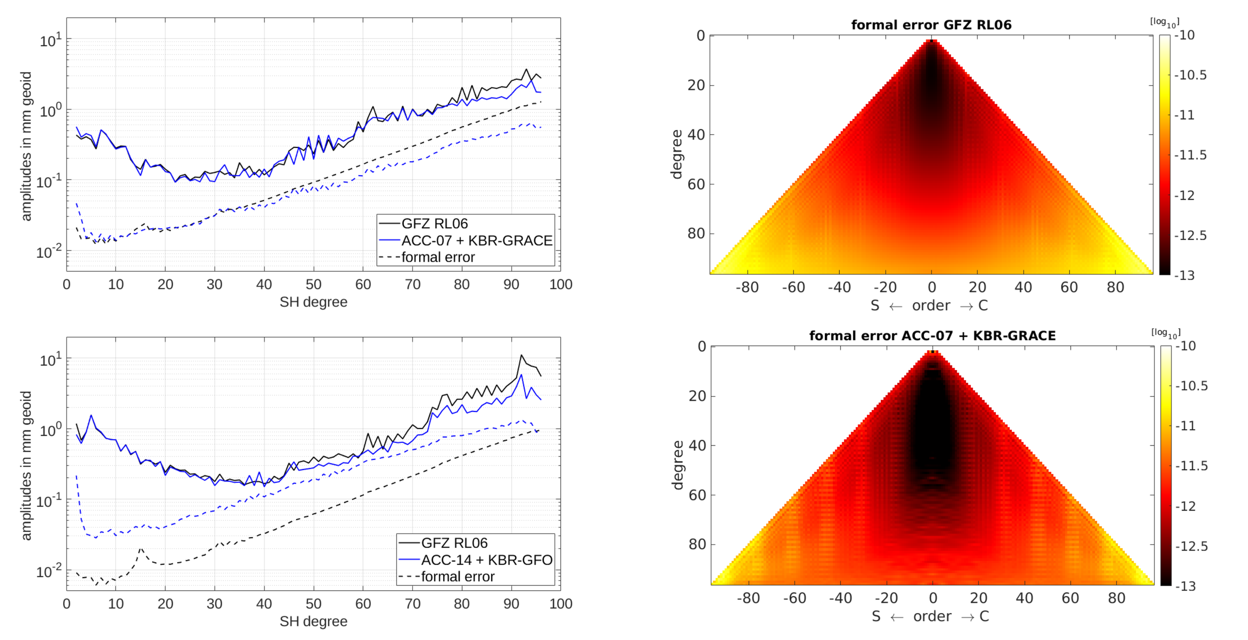

Fig. 2: GRACE/GRACE-FO GFZ solutions with empirical parameters without stochastic modeling (RL06), and without empirical parameters with stochastic modeling (ACC + KBR); left: spherical harmonic (SH) degree amplitudes of the residuals w.r.t. EIGEN-6C4 (solid lines) and formal errors (dashed lines) for Jan. 2007 (top) and Mar. 2019 (bottom) in mm geoid height; right: formal error spectra for Jan. 2007 without (top) and with stochastic modeling applied (bottom).

Optimized space-time parameterization

Main idea

- Data-driven multi-step self-dealiasing approach (DMD) for GRACE and GRACE-FO data processing
- Using daily low resolution gravity fields as additional de-aliasing dataset (Fig. 3)

Method

- Using different daily solutions, different max. SH degree, using gaussian NEQ-weighting schemes for higher resolutions, external daily solutions (ITSG-Grace2018, Kvas et al. 2019)
- Fixing high degree coefficients when estimating daily low degree parameters using different a priori fields (Fig. 4)

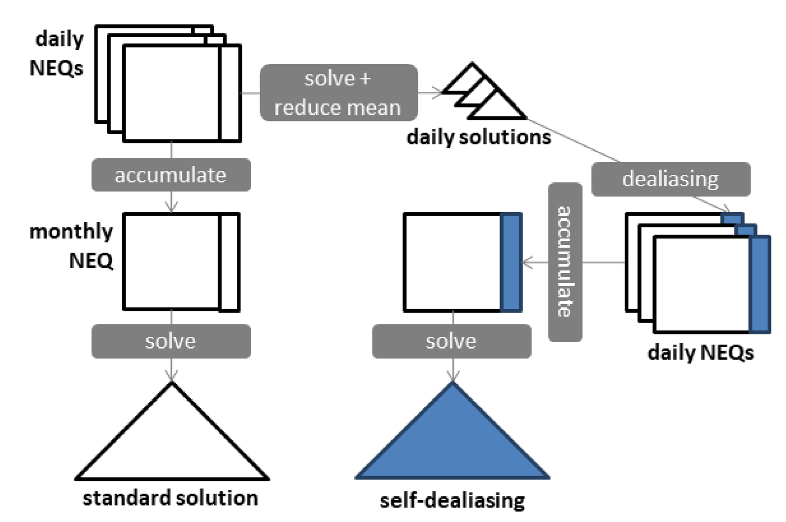

Fig. 3: Processing scheme for monthly gravity field determination comparing the standard RL06 solutions (left) and the DMD (right) based on daily combined low-low and high-low SST normal equation systems (top left).

Results

- Best performance with daily solutions up to max. d/o 12 (DS12), initial setup with fixing high degrees to EIGEN-6C4 (preferably use a static field with reference epoch close to the specific month, cf. Fig. 4)
- Significant noise reduction for all three test years (2007, 2014, 2019) for medium to high SH degrees (Fig. 5)
- Possibly degradation of low degree coefficients (possible solution: constrain mean of daily coefficients to an a priori field)
- Different performance measures maybe caused by different AOD error magnitudes for different periods

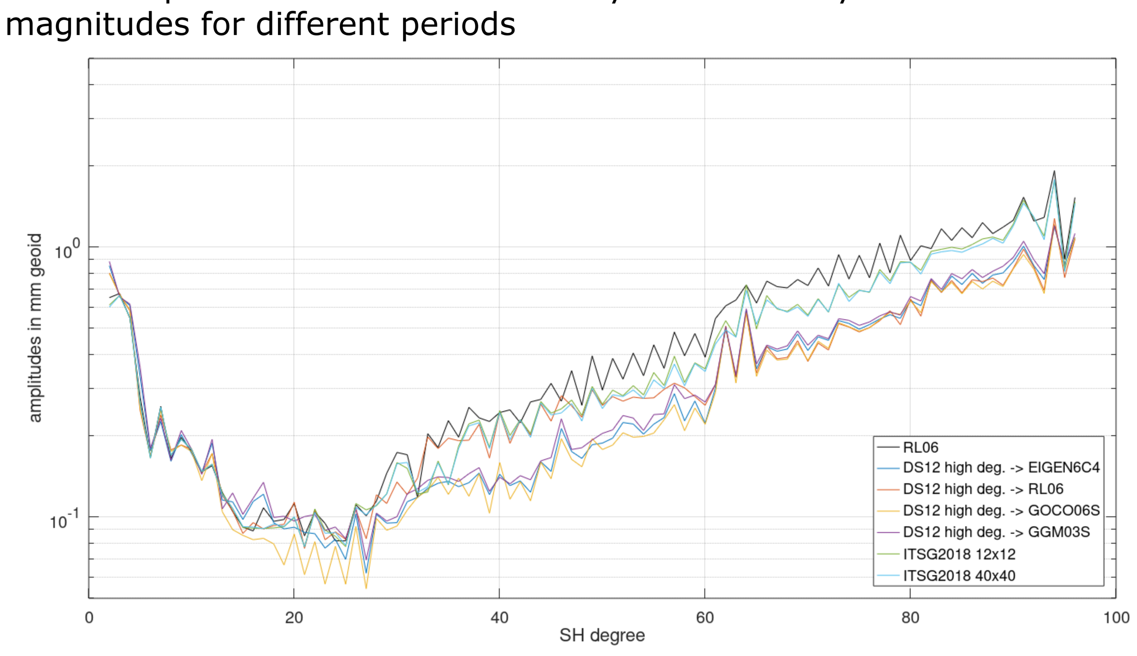

Fig. 4: SH degree amplitudes in mm geoid of Nov. 2014 residuals using different daily solutions for the DMD; the DS12 solutions are estimated while fixing the SH degrees above 12 to different a priori fields; for comparison also the daily ITSG2018 solutions are used up to max. d/o 12 and 40, respectively.

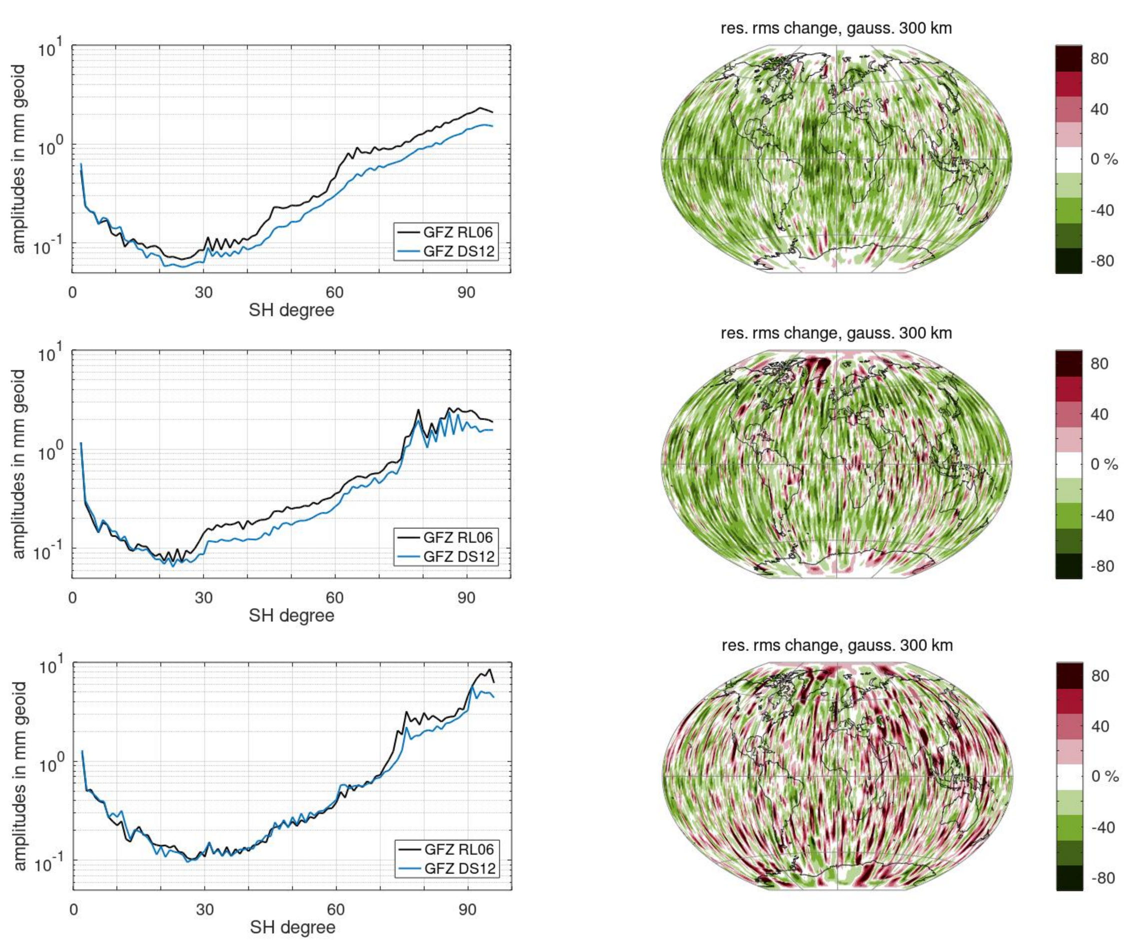

Fig. 5: Comparison of GFZ RL06 solutions without and with the DMD using daily DS12 solutions in terms of SH degree amplitudes in mm geoid (left), and relative residual RMS changes (right) for a 300 km gaussian filter; for each year (from top to bottom: 2007, 2014, 2019) the residual RMS w.r.t. a GFZ GRACE RL06 climatology is analyzed.

Stochastic modeling of ocean tide model

Main idea

- Decorrelation of background model information within GRACE/GRACE-FO Level-2 processing
- References:
  - Kvas et al. (2019) https://doi.org/10.1007/s00190-019-01314-1
  - Abrykosov et al. (2021) https://doi.org/10.1093/gji/ggab421

Method

- Co-estimation of ocean tide (OT) parameters (up to max. d/o 30) using a full variance covariance matrix (VCM) describing the OT errors as constraint
- Applied to 3 years of GRACE data (2007 to 2009)

Results

- More realistic formal errors, i.e. increased for low SH degrees (cf. Fig. 6, left)
- Reduced noise: up to 10 % ocean wRMS reduction for different filters for all months (Fig. 6, center)
- Residual RMS reduction (mainly ocean areas, Fig. 6, right)

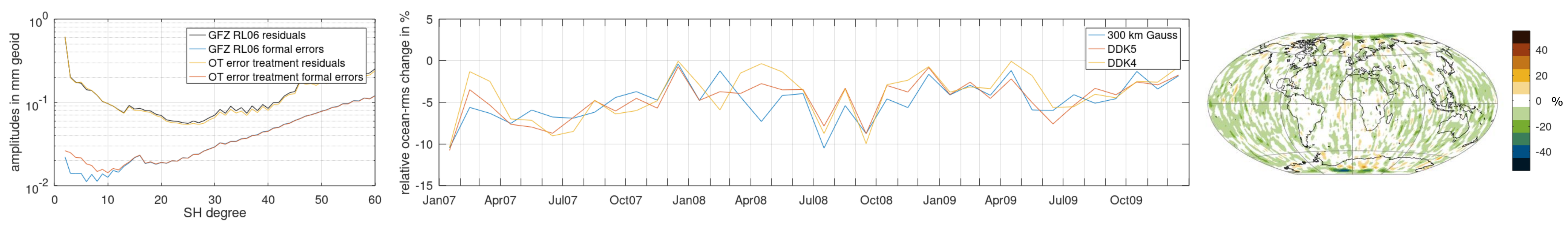

Fig. 6: Comparison of GFZ GRACE RL06 without and with OT error VCM treatment for the years 2007 to 2009; residual RMS w.r.t. to a six-parameter model and formal error RMS;
left: SH degree amplitudes in mm geoid height of the residual RMS (black, yellow) and formal errors (blue, red);
center: relative residual ocean wRMS change in percent applying the OT error VCM treatment for all months for three different filters;
right: relative residual RMS change in percent for the three years (DDK5 filtered).

New version RL06.1 of GFZ GRACE-FO Level-2 products

Background

- The GRACE-FO SDS has recently published a new Level-1B ACC product for GF2
  - ‚ACX' product, available at GRACE-FO archives PODAAC & ISDC
  - hybrid transplant, using data from GF1 and GF2
- RL06.1 is based on ACH1B products for GF2
  - ACH1B is part of the new 'ACX' Level-1B files
  - recommended by the SDS to be used instead of current ACT1B products

Results

- RL06.1 time series shows significantly reduced noise level compared to RL06, in particular for months where the satellites' beta prime angle is close to zero
- ACH1B performs quite similar as the also available alternative ACT1B product from TU Graz

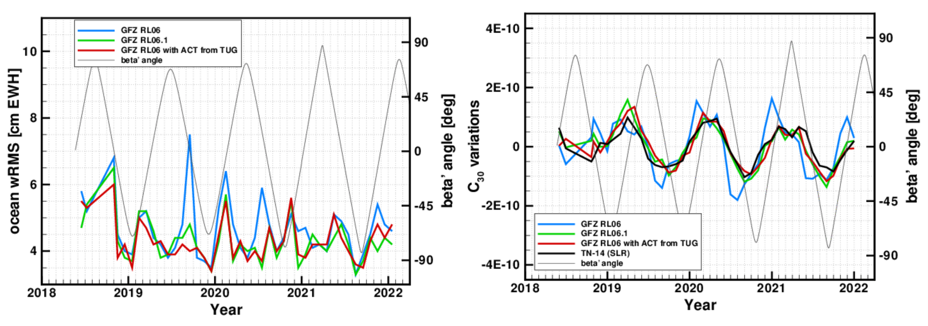

Fig. 7: Comparison of GFZ GRACE-FO RL06.1 (green), RL06 (blue), and an alternative RL06 version using the ACT1B product from TU Graz (red);
left: wRMS over the oceans (DDK5 filtered, residuals relative to a six-parameter model);
right: time variations of the C_{30} coefficient compared to the currently recommended SLR-based replacement C_{30} time series TN-14 (black).

Summary & Outlook

New SDS ACH1B transplant product for GF2 is applied during Level-2 gravity field processing:
GRACE-FO RL06 → RL06.1

Advanced processing strategies indicate additional improvements in gravity field solutions

Main goal with regard to a future **GFZ RL07** time series: **Combination of different new processing strategies** (cf. Fig. 8) in order to obtain improvements in terms of

- reduced temporal aliasing errors
- more realistic formal errors

Further activities planned:

- stochastic modelling of GPS observations
- stochastic modelling of AOD background model

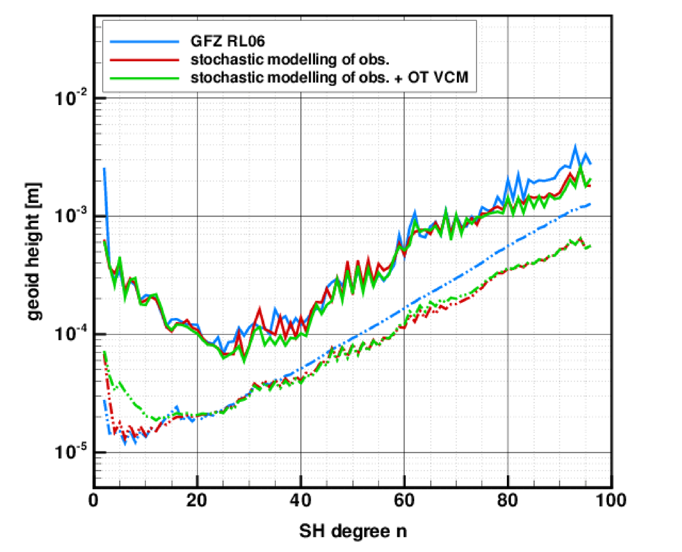

Fig. 8: SH degree amplitudes of solutions combining the methods for stochastic modeling of the range rate observations and the OT background model for January 2007.

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