

GFZ GRACE and GRACE-FO Level-2/-3 Overview

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GRACE/GRACE-FO Science Team Meeting 2024

Potsdam & online, October 8-10

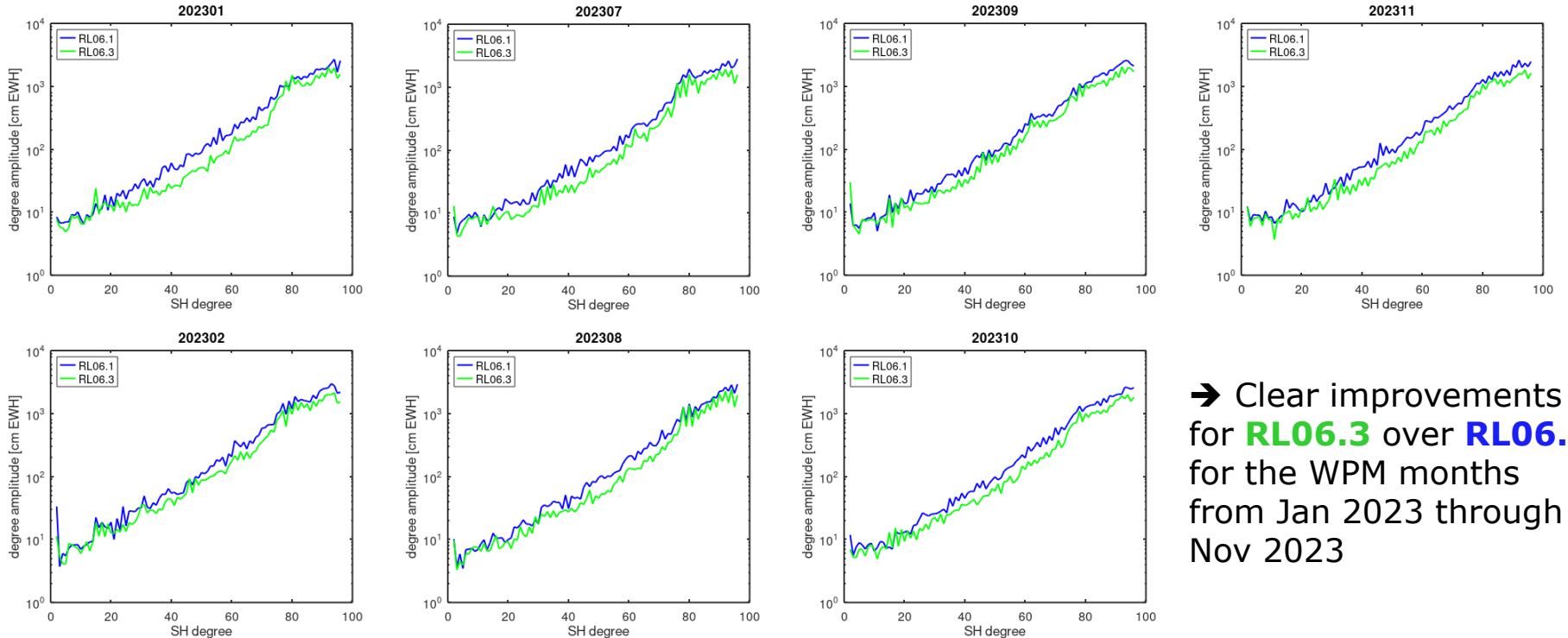
Level-2: Operational GFZ RL06 time series

- **GRACE-FO:**
 - Operational Level-2 processing switched from RL06.1 to RL06.3 with the June 2024 solution (last RL06.1 solution is May 2024)
 - Current Level-2 processing status: 72 GFZ RL06.3 monthly solutions from June 2018 through July 2024
- **Entire GRACE + GRACE-FO GFZ RL06 time series:**
 - 235 monthly solutions, consistently processed
 - Available at ISDC and PO.DAAC archives
 - GFZ RL06/RL06.1/RL06.3 normal equations in SINEX format are provided at ISDC

Level-2: GFZ RL06.3 processing

- Differences compared to GFZ RL06.1:
 - RL06.3 differs only in months with wide-pointing mode (WPM)
 - Jan & Feb 2023, July 2023 through May 2024
 - For these WPM months, GSM products were reprocessed using **improved ACH1B products for GF2** (as provided with the **Level-1B ACX2-bundles**)
 - For all other months, RL06.3 Level-2 products are identical with RL06.1 (only headers and filenames were updated for the users' convenience)
- Adapted parametrization for WPM months (also for RL06.1):
 - Additional piecewise-linear empirical accelerations in along-track and cross-track are estimated once per orbital revolution and only for GF2
 - Usefulness of these additional parameters is assessed for each month
 - Selected parametrization for published GSM products is documented in **GFZ GRACE-FO RL06.3 Level-2 Release Notes**

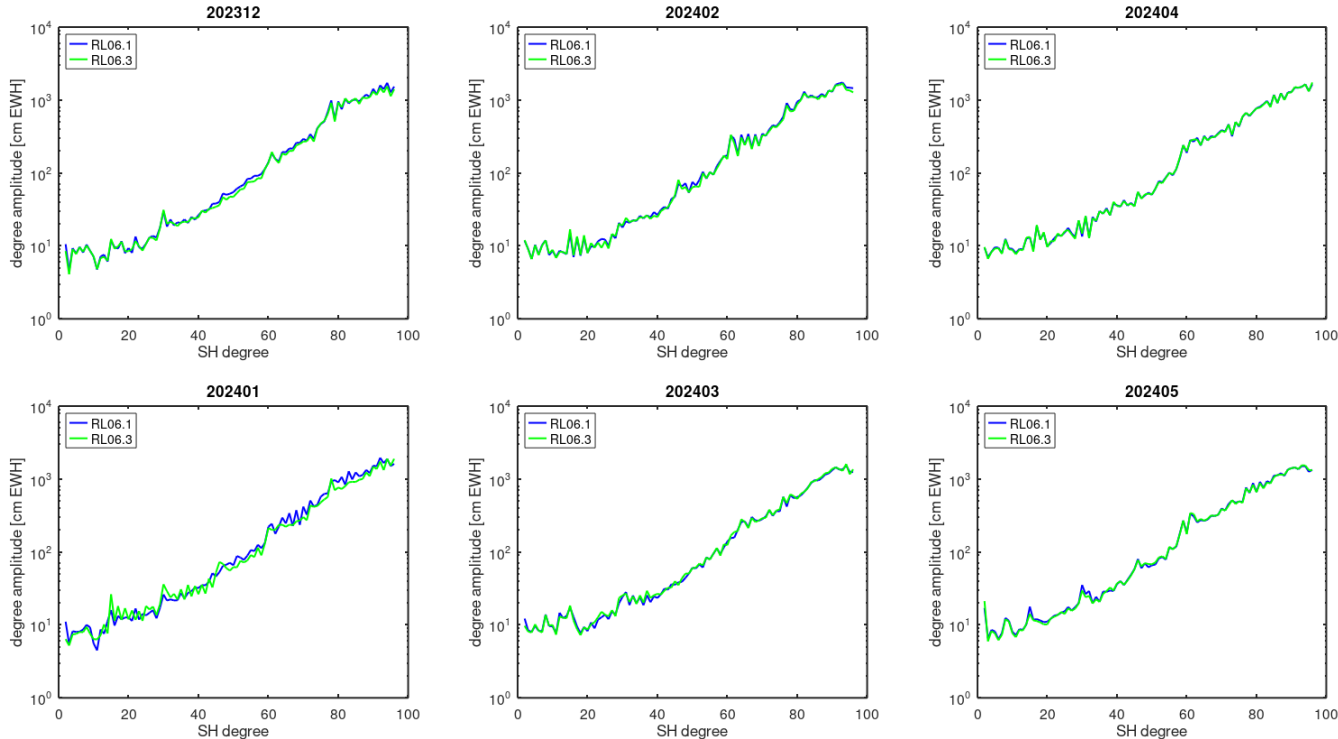
Level-2: GFZ RL06.3 assessment



➔ Clear improvements for **RL06.3** over **RL06.1** for the WPM months from Jan 2023 through Nov 2023

Difference degree amplitudes relative to a GRACE/GRACE-FO climatology

Level-2: GFZ RL06.3 assessment

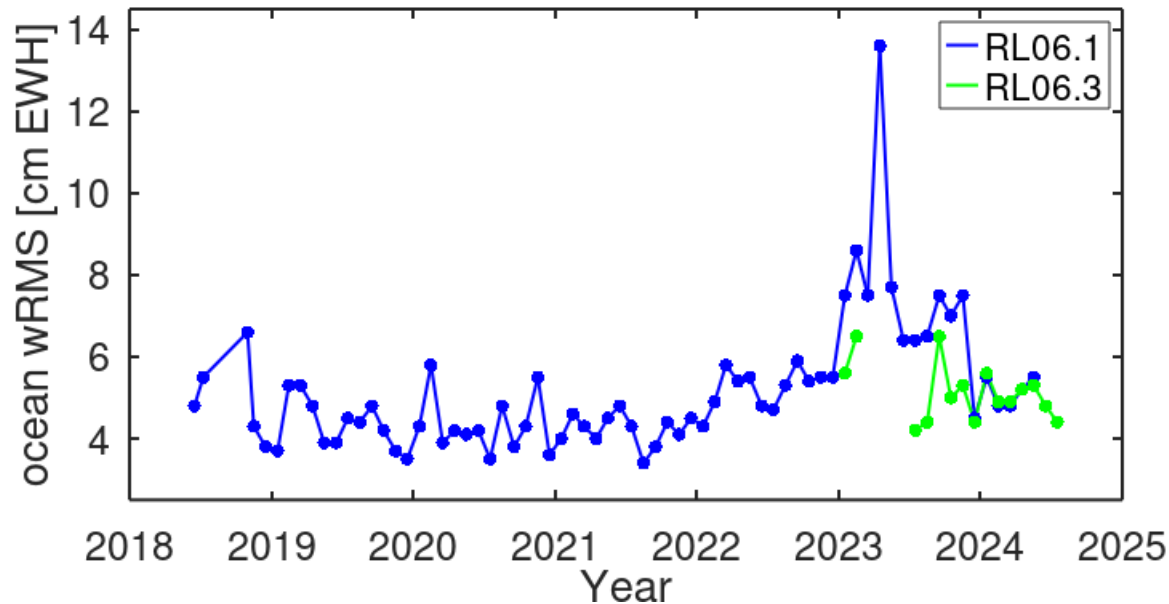


➔ Only little differences between **RL06.3** and **RL06.1** for the WPM months since Dec 2023:

- From here on, ACH1B released with the ACX-bundles was already very close to the ACX2-version of ACH1B

Difference degree amplitudes relative to a GRACE/GRACE-FO climatology

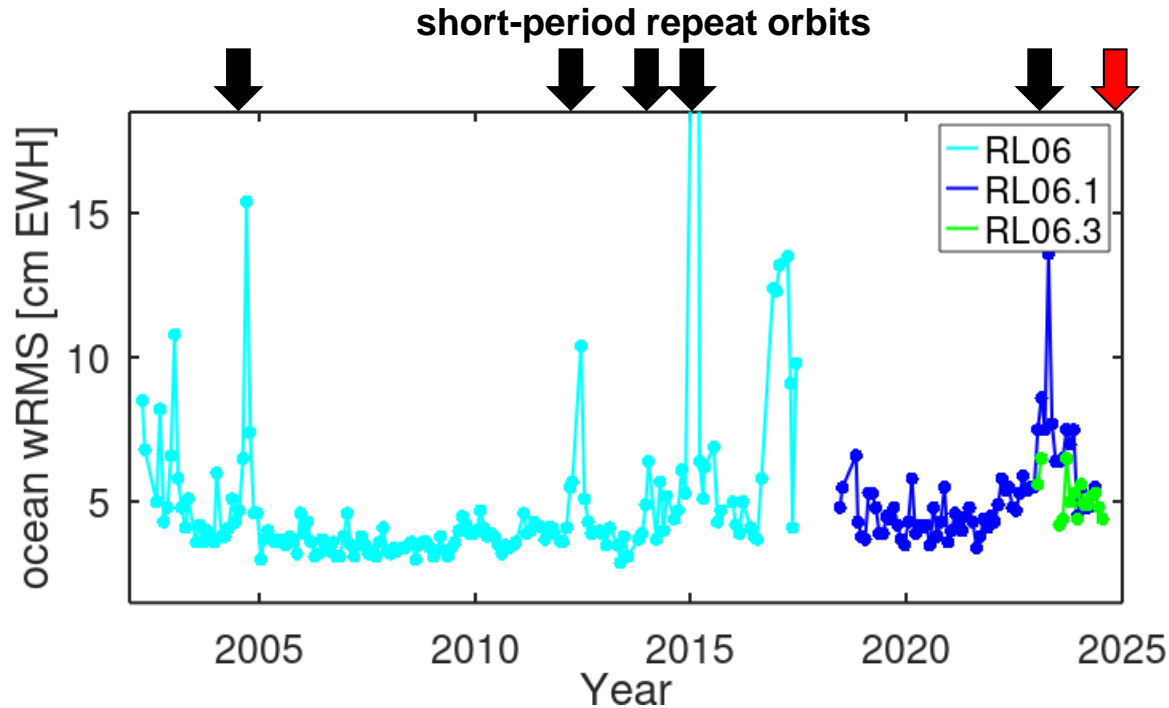
Level-2: GFZ RL06.3 assessment



wRMS over open ocean (DDK5 filtered, residuals relative to a GRACE/GRACE-FO climatology)

- Clear improvements for **RL06.3** over **RL06.1** for the first WDB months through Nov 2023
- “Usual” GRACE-FO noise level in most recent months despite increasing solar activity

Level-2: GFZ RL06/RL06.3 noise level

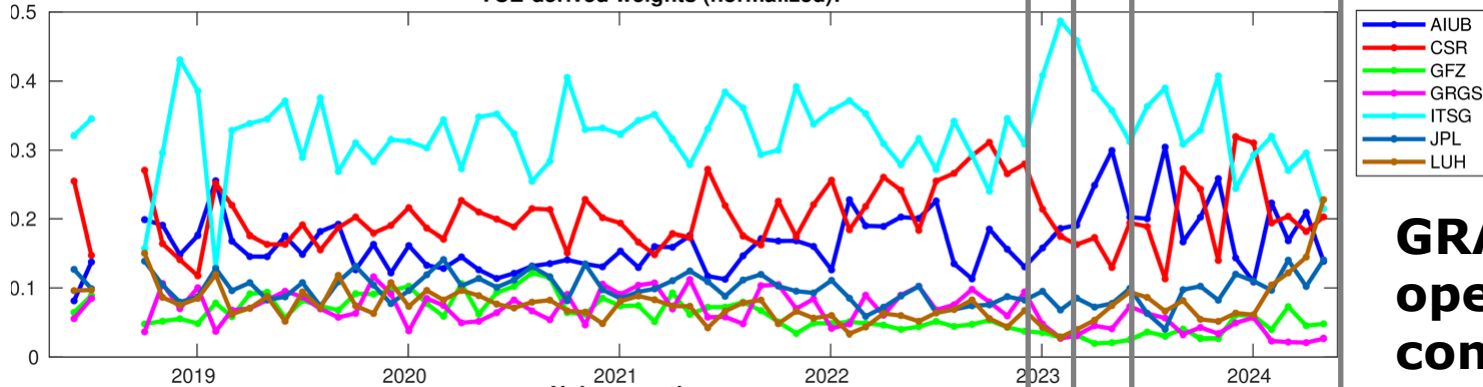


wRMS over open ocean (DDK5 filtered, residuals relative to a GRACE/GRACE-FO climatology)

- **GRACE-FO** shows quite consistent overall noise level compared to **GRACE**, almost reaching the level of the “best” GRACE years (2005 - 2012)
- Large outliers in the time series mostly due to impact of repeat orbits

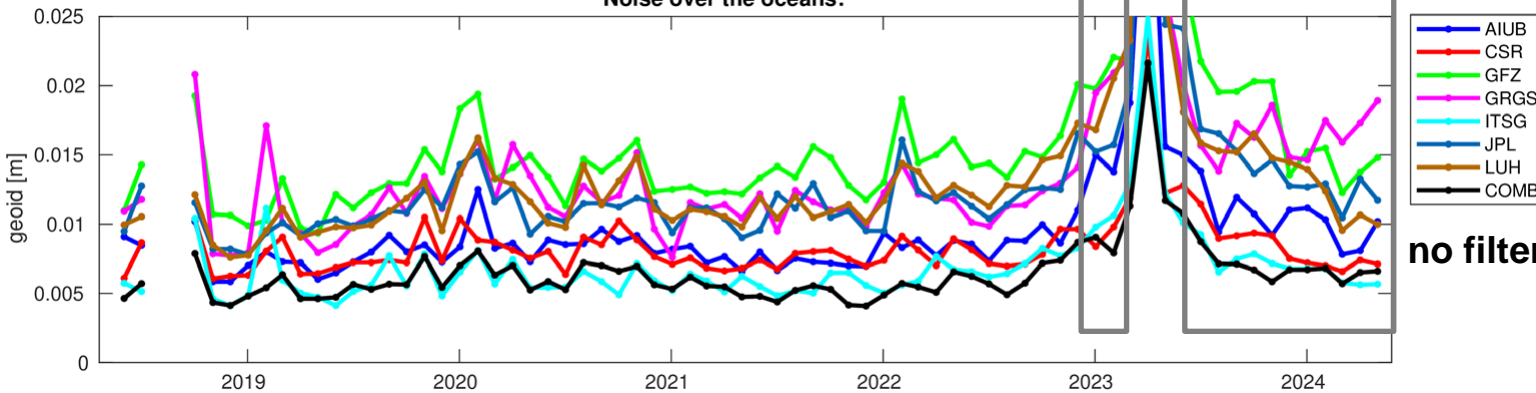
Level-2: RL06.3 from COST-G perspective

VCE-derived weights (normalized):



**GRACE-FO RL02
operational
combination**

Noise over the oceans:



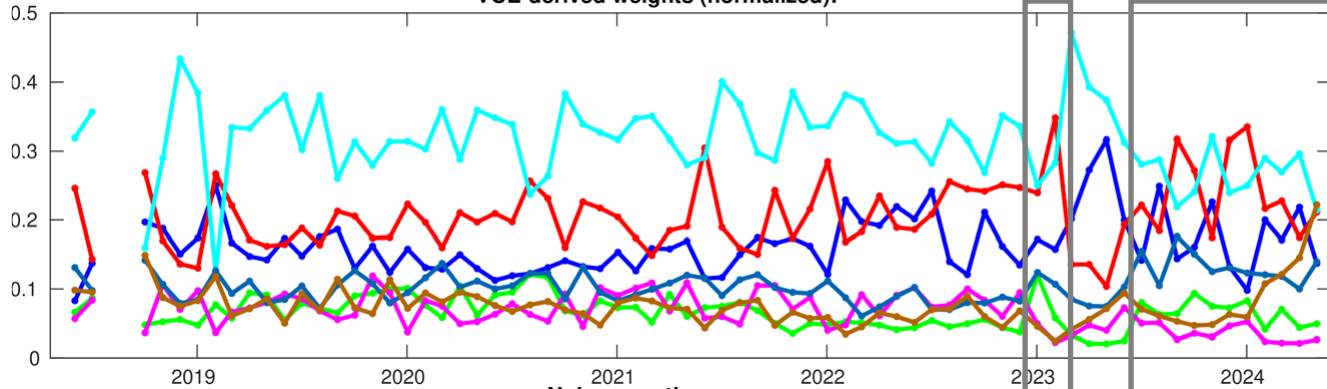
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Courtesy:
U. Meyer
(AIUB)



Level-2: RL06.3 from COST-G perspective

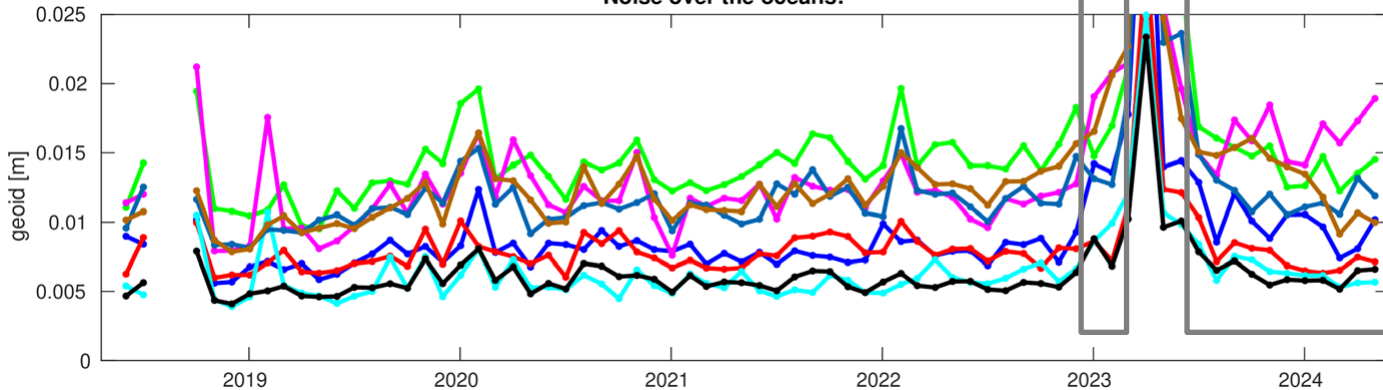
VCE-derived weights (normalized):



- AIUB
- CSR63
- GFZ63
- GRGS
- ITSG
- JPL63
- LUH

GRACE-FO test combination incl. SDS RL06.3

Noise over the oceans:



- AIUB
- CSR63
- GFZ63
- GRGS
- ITSG
- JPL63
- LUH
- COMB

no filter

Courtesy:
U. Meyer
(AIUB)



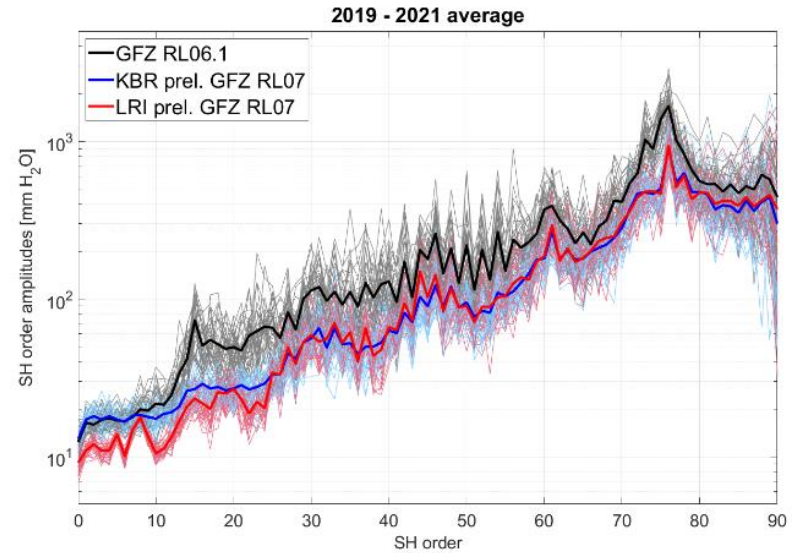
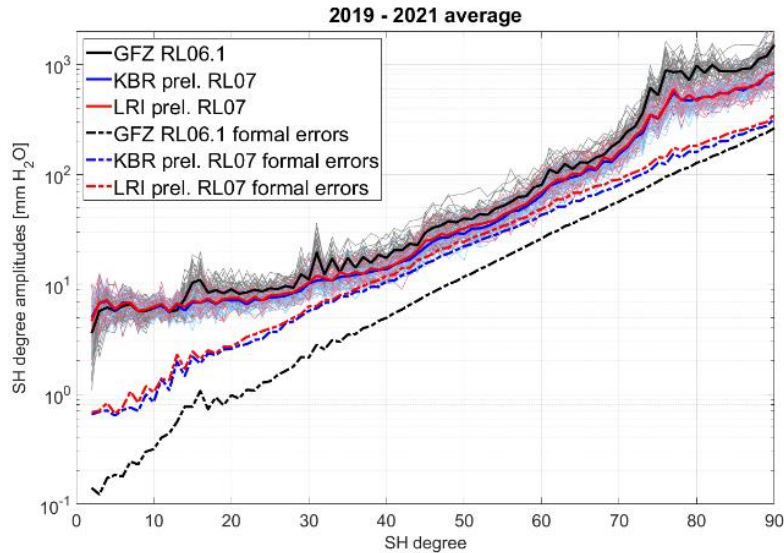
Level-2: GFZ RL07 reprocessing status

Changes in processing compared to RL06:

- Stochastic modeling of background models
 - Making use of available full variance-covariance matrices (VCMs) for ocean tide (OT) and non-tidal atmospheric and oceanic de-aliasing (AOD) models
 - **Related posters:** *M. Murböck et al. (GSTM2024-36, P5)*
J. Wilms et al. (GSTM2024-6, P7)
- Stochastic modeling of observations
 - Using a priori noise models for KBR/LRI and GPS
 - Using KBR/LRI post-fit residuals in a 2nd iteration
- Parametrization and other processing choices
 - No estimation of empirical parameters
 - Optimization of relative weighting between KBR/LRI and GPS observations → variance component estimation (VCE)

Level-2: GFZ RL07 reprocessing status

Results for 3-year test period 2019 – 2021:



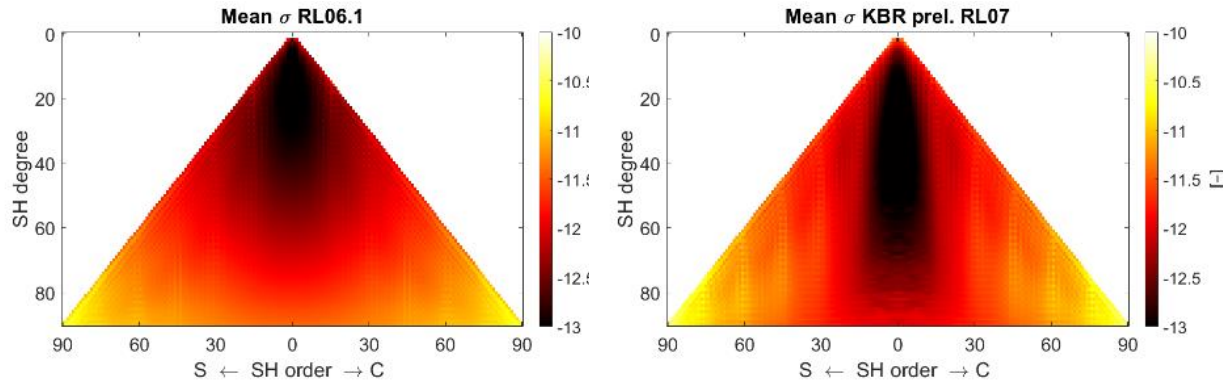
Difference degree (left) and order (right) amplitudes relative to COST-G climatology

More insights into LRI Level-2 processing at GFZ → *oral presentation by M. Hauk this afternoon (GSTM2024-17, Session A.2, Oct 8, 5:15pm)*

Level-2: GFZ RL07 reprocessing status

Results for 3-year test period 2019 – 2021:

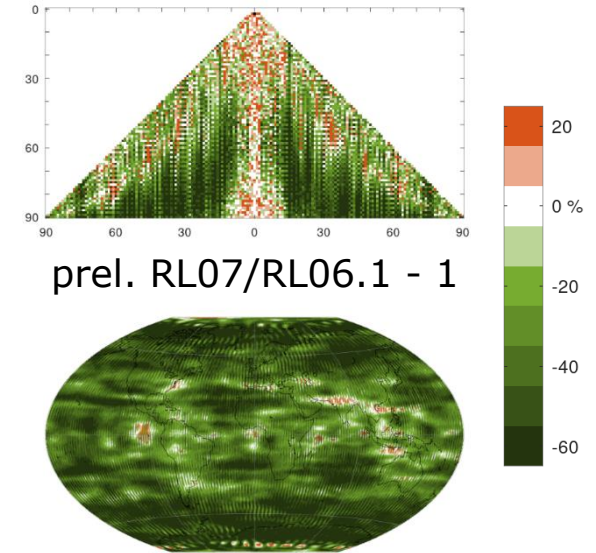
Mean formal errors:



Improvements of RL07 over RL06:

- Reduced noise for medium and high degrees/orders
- Clear reduction of residual RMS
- More realistic formal errors

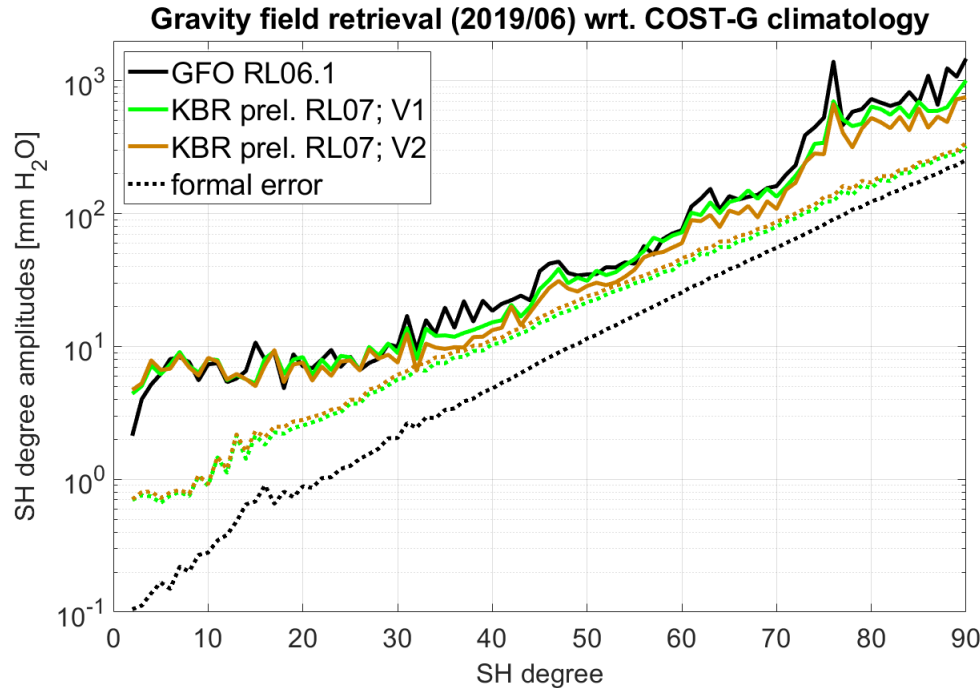
Relative change of RMS:



unfiltered residuals relative to COST-G climatology

Level-2: GFZ RL07 reprocessing status

Impact of individual processing changes on gravity field solution:



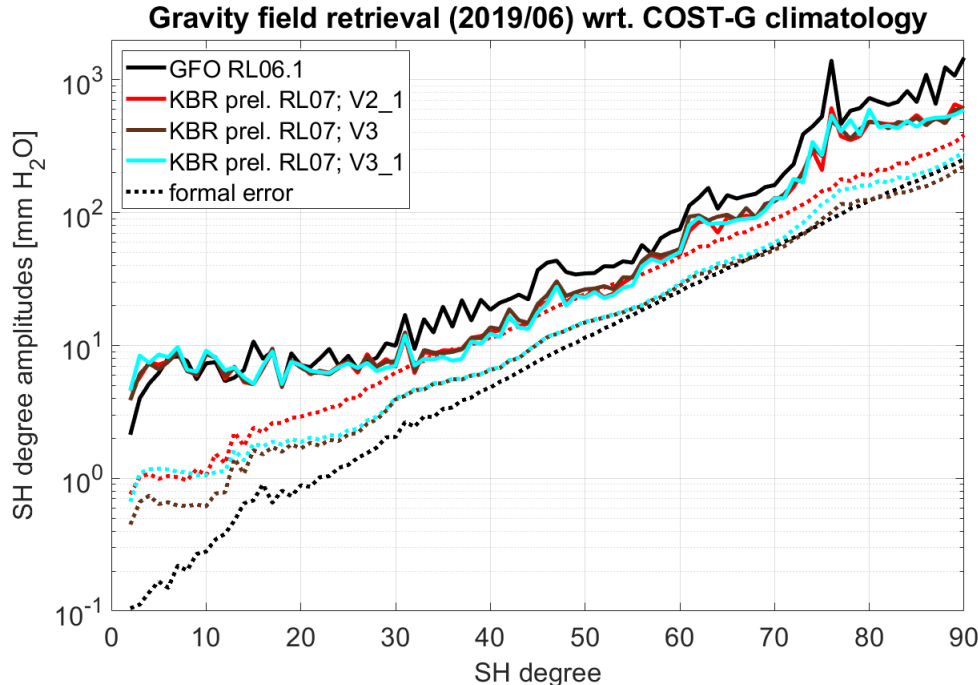
- Stochastic modeling of observations & optimal weighting based on VCE already significantly better than RL06 (V1)
- Adding stochastic modeling of OT/AOD models brings further improvement (V2)

Ocean RMS (cm EWH)

RL06.1:	4.59
prel. RL07 V1:	3.84
prel. RL07 V2:	3.24

Level-2: GFZ RL07 reprocessing status

Contribution of individual processing changes to overall improvement:



- Stochastic modeling of observations based on post-fit residuals leads to more pronounced wave structure of formal error degree amplitudes (V3 vs V2_1)
- However, formal errors become smaller (too optimistic?) again
- This can partly be avoided when optimally scaling the OT VCM (V3_1)

Level-2: GFZ RL07 reprocessing status

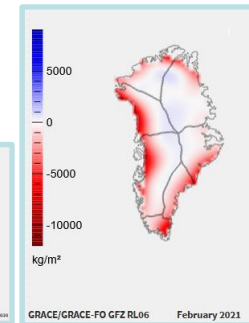
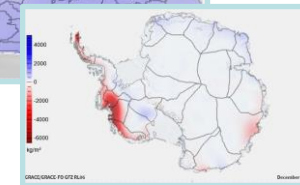
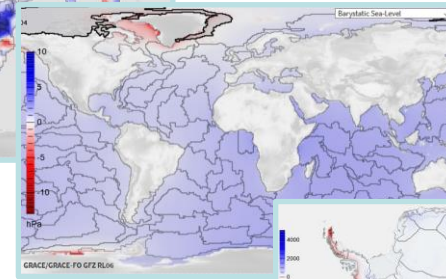
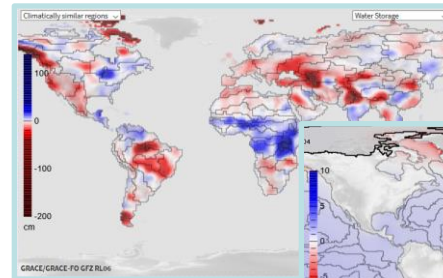
- Further Plans:
 - Assessment of most recent ocean and atmospheric tide models
 - Investigate potential benefit of taking temporal correlations of the AOD model into account → see poster by *M. Murböck et al. (GSTM2024-36, P5)*
 - Tests with updated version the OT VCM
 - Refine optimal strategy for relative weighting between KBR/LRI and GPS
- Planned release of GFZ GRACE/GRACE-FO RL07: Fall 2025

Level-3: GravIS portal



gravis.gfz-potsdam.de

- Dedicated mass change products for:
 - Terrestrial water storage over non-glaciated regions (TWS)
 - Bottom pressure variations in the oceans (OBP)
 - Ice-mass changes in Antarctica and Greenland (in collaboration with AWI & TU Dresden)



- As an additional product, the “Global Gravity-based Groundwater Product” (G3P) prototype is available



Level-3: GravIS products



- Overview on available products:
 - Level-2B:
 - **SH coefficients**, with standard **corrections applied**: (optional) VDK filtering, replacement of specific low degree harmonics, geocenter, GIA, S2 tidal alias signal)
→ <ftp://isdcdftp.gfz-potsdam.de/grace/GravIS/>
 - Level-3:
 - **Gridded data** (NetCDF format) → <ftp://isdcdftp.gfz-potsdam.de/grace/GravIS/>
 - **Regional averages** (csv files) → *directly from corresponding GravIS subpages*
 - Both can contain several variables, such as, e.g., uncertainties
- All GravIS products
 - are extended on a regular basis
 - are occasionally updated to incorporate Level-2/3 processing improvements

Level-3: Product updates



- GravIS Level-2B/Level-3 products will be updated within the next few weeks to incorporate new RL06.3 Level-2 time series
- New version v1.12 of G3P products is available
 - Temporal coverage has been extended until September 2023

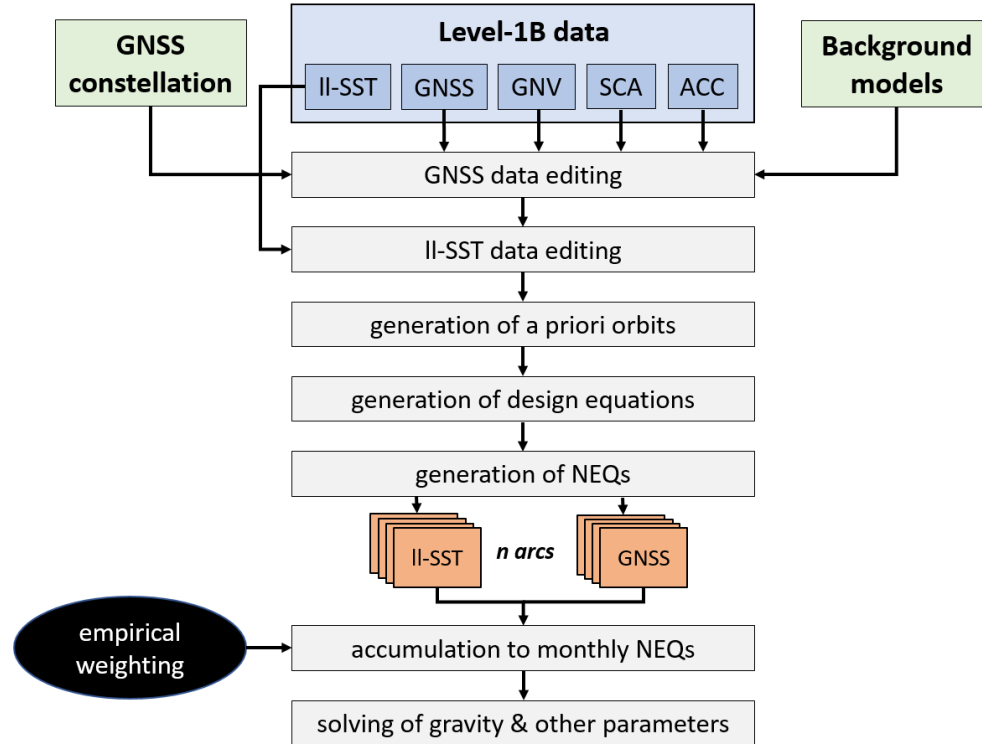
Summary

- Operational GRACE-FO Level-2 processing has switched from RL06.1 to RL06.3
 - Improvements for months in wide-pointing mode due to new SDS hybrid transplant product (ACH1B) provided with ACX2-bundles
- Ongoing work on improved RL07 Level-2 time series
 - Preliminary solutions show reduced noise and more realistic formal errors
- GFZ Level-3 mass change products are provided at GravIS portal
 - Updated version of products incorporating RL06.3 Level-2 time series soon to come
 - New version of G3P groundwater product is available

Backup

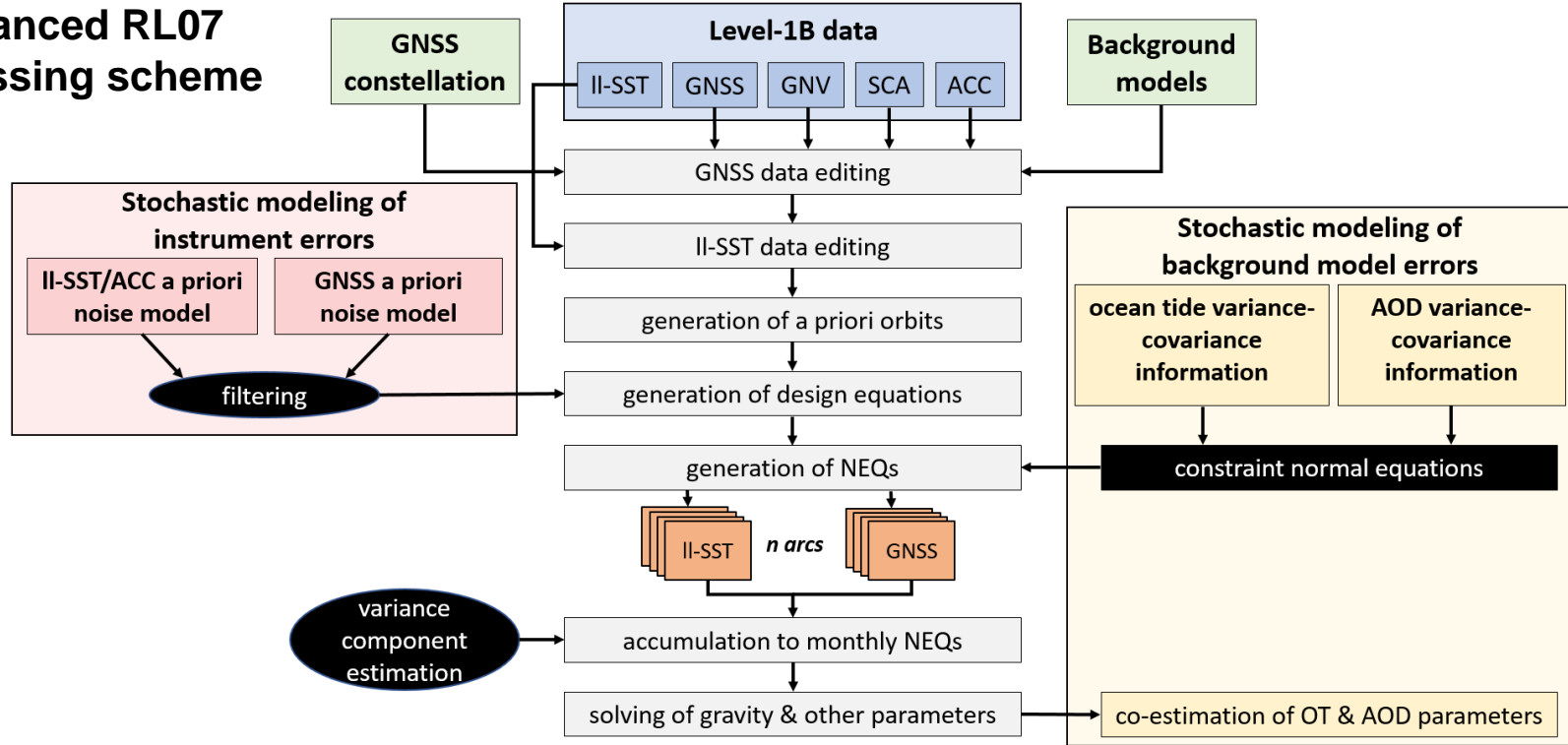
Level-2: GFZ RL07 reprocessing status

Current RL06 processing scheme



Level-2: GFZ RL07 reprocessing status

Enhanced RL07 processing scheme



Level-3: GravIS portal



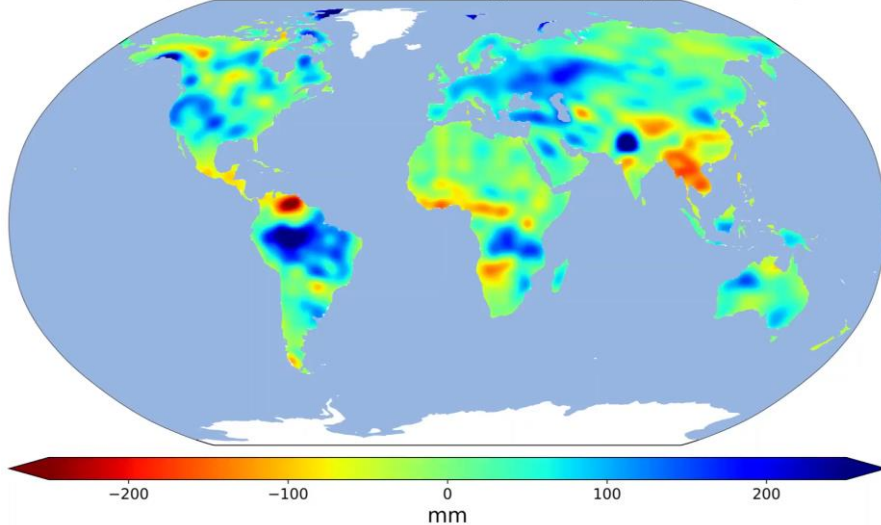
- GFZ's web portal to provide user-friendly Level-3 products based on monthly GRACE/-FO Level-2 products
 - Products can be interactively viewed and are freely available for download
 - Two versions, based on different Level-2 time series:
 - 1) GFZ RL06/RL06.1
 - 2) COST-G RL01/RL02 (Combination Service for Time-variable Gravity Fields, <https://cost-g.org/>)

Level-3: G3P groundwater product



gravis.gfz-potsdam.de

Monthly Groundwater Storage Anomaly (04-2002)



The EU-funded project G3P developed the **first satellite-based global-scale data set of groundwater storage anomalies (GWSA)**, obtained by **subtracting satellite-based water storage compartments from GRACE/-FO monthly TWS anomalies**

→ Rather a **Level-4** product

Groundwater = TWS - Glaciers - Snow - Soil Moisture - Surface Water Storage

Güntner, A. et al. (2024): Global Gravity-based Groundwater Product (G3P). V. 1.12. GFZ Data Services. <https://doi.org/10.5880/G3P.2024.001>



Level-3: G3P groundwater product



- As for the other GravIS products, two different data representations are provided:
 - Gridded data (NetCDF format)
 - Regional averages (csv files)
- G3P products
 - Contain data for all individual WSCs including their uncertainties
 - Represent anomalies relative to the long-term mean 2002/04 – 2020/12
 - Are based on GRACE/-FO TWS anomalies derived from COST-G Level-2 products
 - Are not yet in operational mode (fixed period: 2002/04 – 2023/09)
- For further details see **gravis.gfz-potsdam.de/gws**
 - **Users are encouraged to test this new data set and provide feedback!**

