# Processing strategies for the GFZ GRACE/GRACE-FO Level-2 data release 07

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# Motivation

- Current GFZ RL06 GRACE/-FO processing standards have not been changed for > 6 years ➔ Reprocessing of an improved GFZ RL07 time series is ongoing, aiming at
  - Reduced noise level of gravity field solutions
  - Reduced temporal aliasing errors
  - More realistic formal error estimates

- In order to reach these goals, we apply an improved stochastic modeling of observations (KBR/LRI/GPS) and background model errors (AO de-aliasing)

# Changes from RL06 to RL07

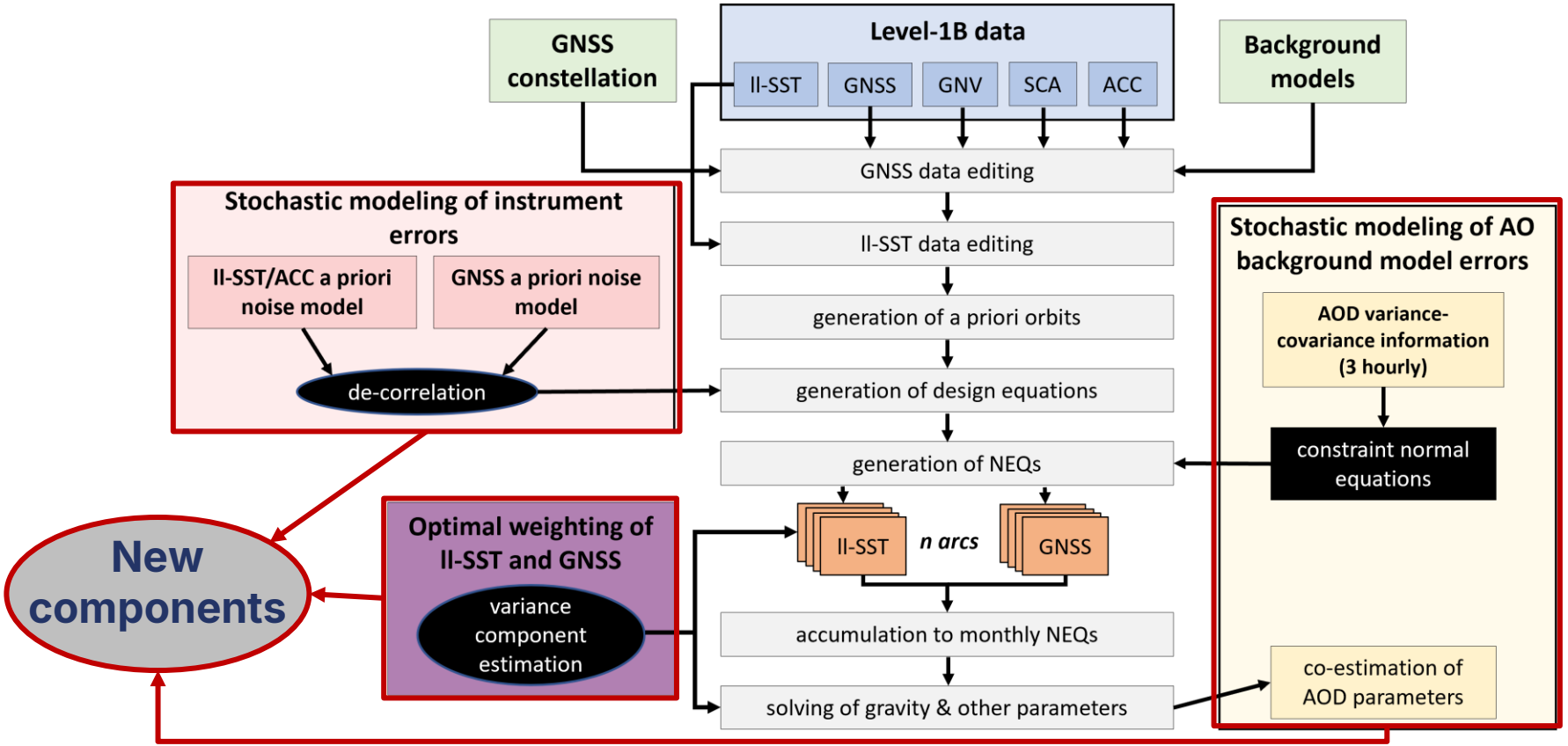
- Stochastic modeling of background model errors
  - Making use of available full variance-covariance matrix (VCM) for non-tidal atmospheric and oceanic de-aliasing (AOD) model *(Wilms et al. 2025, Shihora et al. 2023)*
  - Update: VCMs for the ocean tide parameters are currently not used. Compared to previous tests, no impact seen for gravity field retrieval anymore due to the update of the ocean tide background model from FES2014 to a mixed model including contributions from GOT5.6, FES2022 and TiME22

- Stochastic modeling of observations
  - Using a priori noise models for KBR/LRI and GPS *(Murböck et al. 2023)*
- Parametrization and other processing choices
  - No estimation of empirical parameters
  - Optimization of relative weighting between KBR/LRI and GPS observations ➔ variance component estimation (VCE)

# Changes from RL06 to RL07

| | RL06 | RL07 |
|---|---|---|
| **Instrument data** | | |
| GRACE | JPL v02 (ACC1B, GPS1B) & v03 (ACC transplant, KBR1B, SCA1B) | reprocessed JPL v05 L1B products for both missions (not yet included in the RL07p solutions presented here) |
| GRACE-FO | JPL v04 (ACT1B, ACH1B, GPS1B, KBR1B/LRI1B, SCA1B) | |
| GPS constellation | conform with ITRF2014/IGS14 (conform with ITRF2020/IGS20 since 2022/12) | conform with ITRF2020/IGS20 (currently being processed, not yet included in the RL07p solutions presented here) |
| **Background models** | | |
| Static gravity field | EIGEN-6C4 | XGM2019e |
| Non-tidal atmospheric and oceanic mass variations | AOD1B RL06 | AOD1B RL07 |
| Ocean tides | FES2014 | Mixed model (mix of tidal constituents from GOT5.6, FES2022 and TiME22) |
| Atmospheric tides | Biancale & Bode | TiME22 |

# GFZ RL07 processing scheme



# Current status of RL07 reprocesing

- Final RL07 L2 gravity field products not yet available due to the missing JPL v05 L1B products and the GPS constellation to be updated

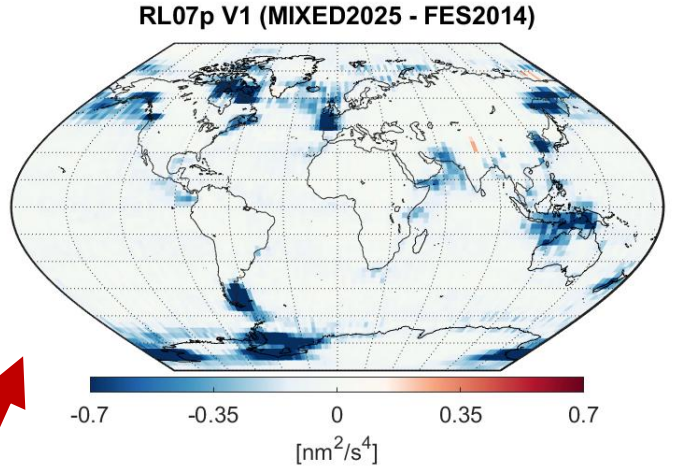
- Preliminary RL07 L2 gravity field products presented here are
  - Version 1 (V1) solutions including:
    - the application of stochastic modeling of observations for KBR/LRI and GPS by means of variance-covariance matrices (VCMs) → de-correlation of NEQ system
    - the application of arc-wise iterative Variance Component Estimation (VCE)

  - Version 2 (V2) solutions additionally including:
    - the application of the AOD variance-covariance information

# Ocean tide model update for RL07

- For GFZ RL07, a new tide model formalism has been implemented (see https://www.tugraz.at/institute/ifg/downloads/ocean-tides)
- Reference case: FES2014 (tide model formalism as originally implemented in our software → see presentation of C. Dahle: On ocean tide background modelling during GRACE gravity field determination)
- New models tested:
  - EOT20
  - FES2022
  - GOT5.6
  - Mixed model (mix of tidal constituents from GOT5.6, FES2022 and TiME22)

  → performs best, up to 10% error reduction at L2a fields
- Analysis of post-fit residuals evaluated over one entire year in terms of global grids of 3x3 degree bins of variance differences




Improvements for the mixed model are shown in blue

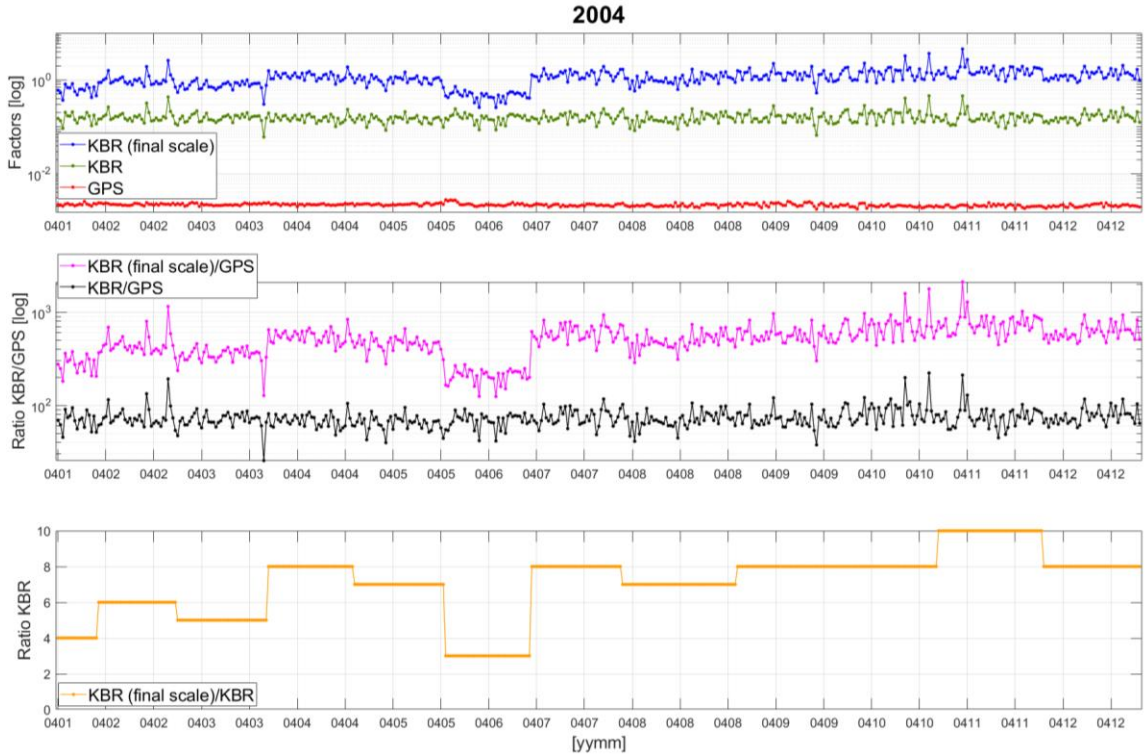
# Preliminary RL07 results: weighting factors for KBR/GPS

- Weighting factors from arc-wise VCE for KBR/GPS (example: year 2004)

Weighting factors for KBR and GPS NEQs per arc after 2 iterations of VCE. The final KBR weights are obtained empirically by further up-/downweighting of KBR NEQs relative to GPS aiming at the smallest oceanRMS

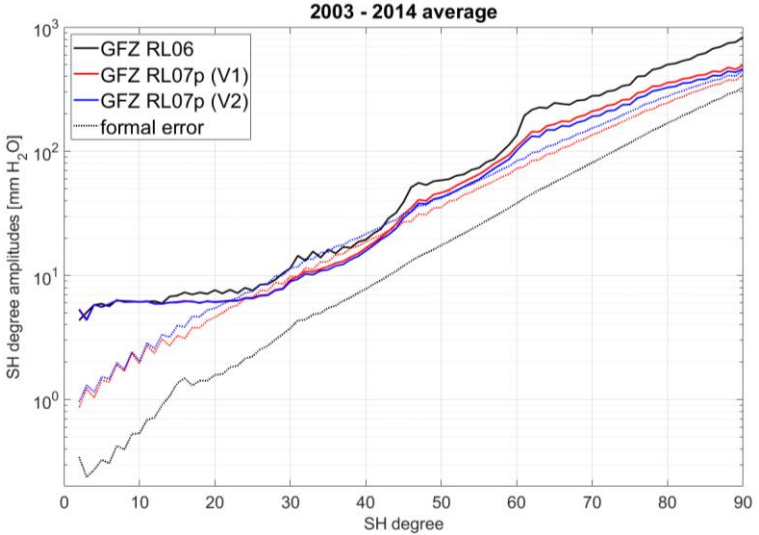
Average ratio between KBR and GPS is ~75
Average ratio between KBR (final scale) and GPS is ~527

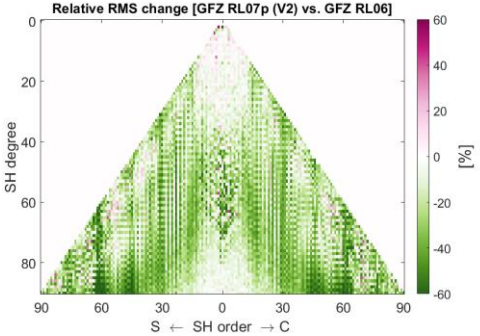
The range for the empirically derived KBR scaling factors for optimized L2a fields is between 1 and 10 for the majority of the GRACE months

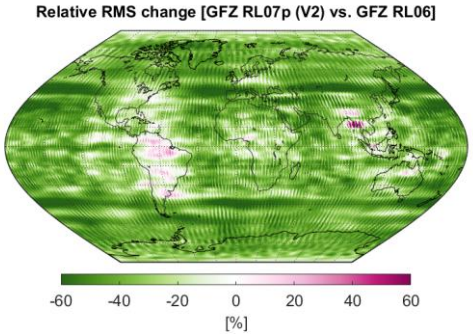


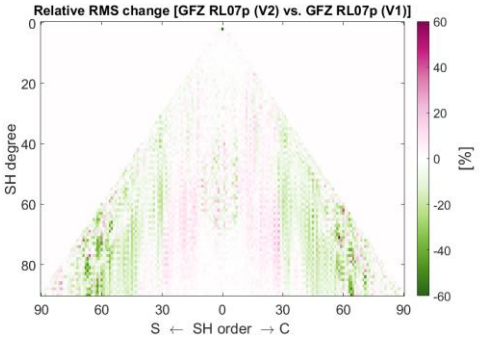
# Preliminary RL07 results: GRACE – KBR

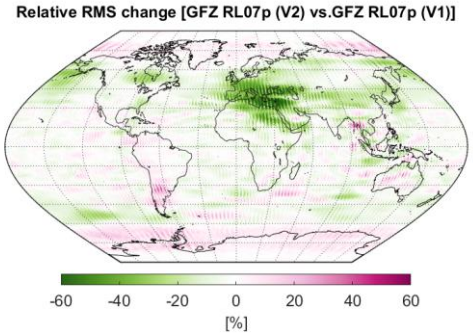
- Time period: 2003 - 2014
- Unfiltered residuals relative to COST-G climatology



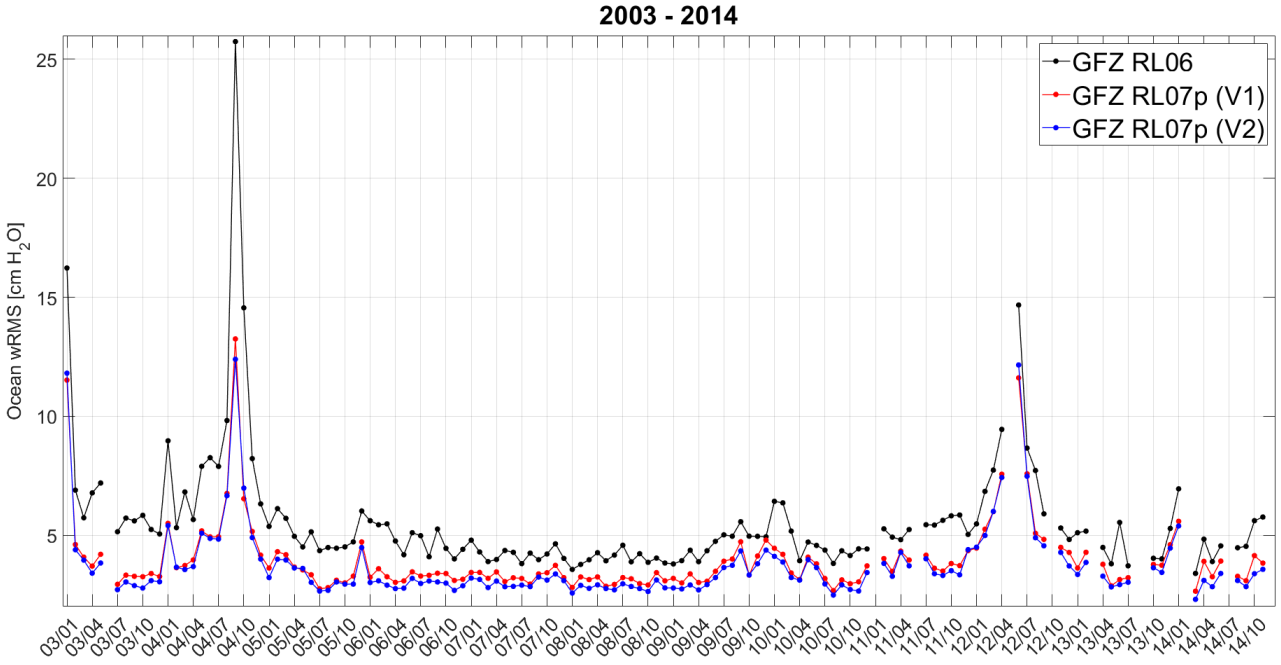




Improvements of RL07 over RL06:

- Reduced noise from d/o 15 onwards
- More realistic formal errors
- Largest improvement for V1 due to instrument noise VCMs

# Preliminary RL07 results: GRACE – KBR

- Time period: 2003 - 2014
- Residual ocean RMS (relative to COST-G climatology, 300 km Gaussian smoothing)

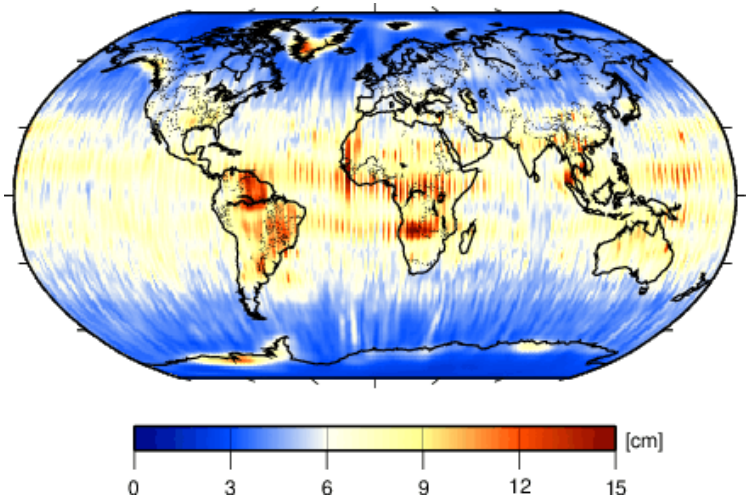



| Metric | RL06 | RL07p (V2) |
|---|---|---|
| σ [cm EWH] | 2.63 | 1.59 |
| Mean [cm EWH] | 5.52 | 3.71 |
| **Improvement of V2 wrt. RL06:** | | |
| Minimum: 10.0% | | |
| Maximum: 52.4% | | |
| Mean: 31.8% | | |

# Preliminary RL07 results: GRACE – KBR

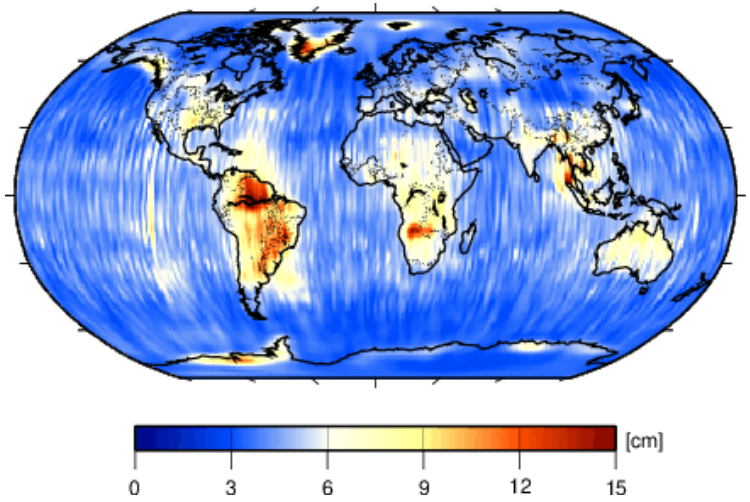
- Time period: 2003 - 2014
- RMS variability (relative to COST-G climatology, 300 km Gaussian smoothing)

GFZ RL06




Ocean RMS: 6.2 cm EWH

GFZ RL07p




Ocean RMS: 4.2 cm EWH

# Preliminary RL07 results: GRACE-FO – LRI

- For GRACE-FO, in addition to the solutions based on KBR observations, we also plan to release fields which are based on LRI observations

  ➔LRI fields will be released later than KBR fields

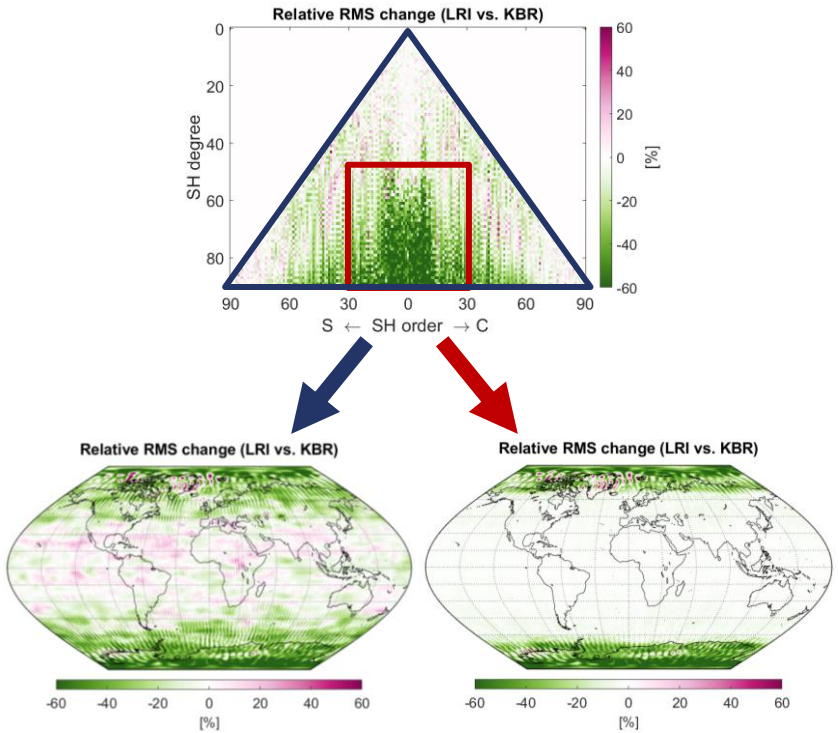
- LRI observations are available until 07/2023. Since then, no LRI measurements could be generated in science mode due to the fact that the satellites operate in wide-pointing mode

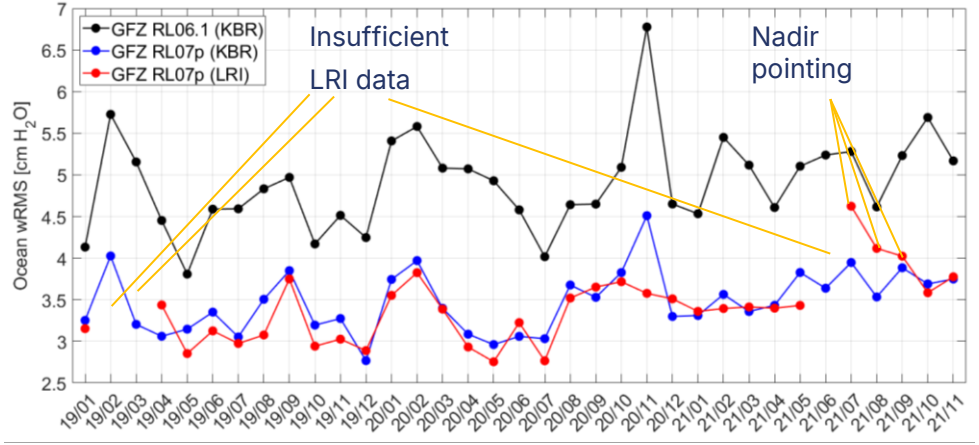
- The LRI has a much higher measurement accuracy compared to the KBR (factor ~1000). However, the potential of the LRI cannot be fully exploited, at least for the time-varying gravity field due to the dominating temporal aliasing error sources

  ➔However, LRI observations might be beneficial for static gravity field generation

# Preliminary RL07 results: GRACE-FO – LRI

- GRACE-FO LRI time period 2019 - 2021



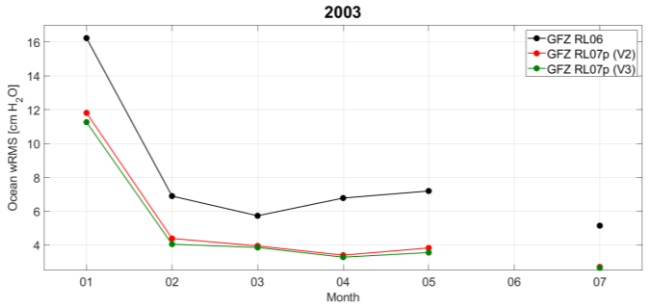



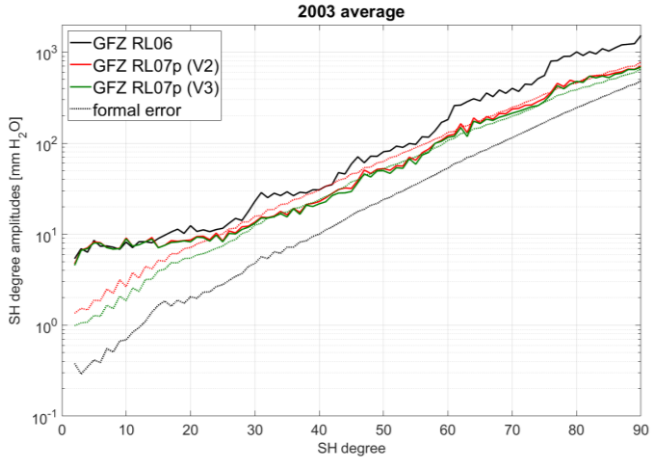

- Benefit from LRI due to less instrument noise is reflected in the high degree spectrum at zonal and near-zonal coefficients
- Spatially, this is related to high latitude areas where the density of observations is largest

# Outlook (Processing strategy for RL07)

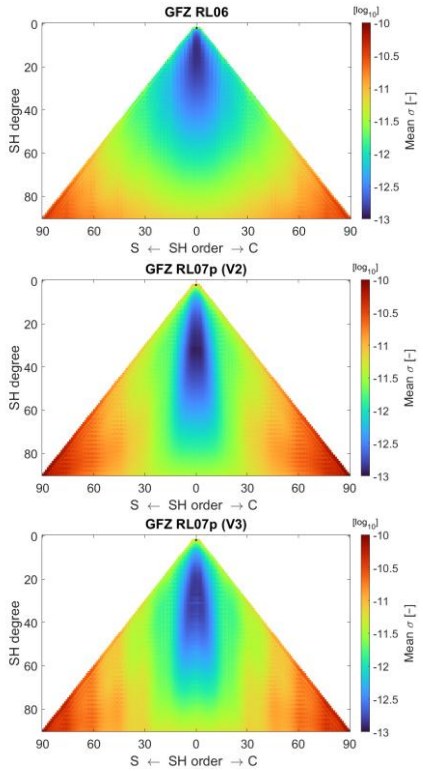
- Final RL07 L2 gravity field products will include
  - ➢ JPL v05 L1B products
  - ➢ Re-processed GPS constellation
  - ➢ Updated ocean tide background model including residual tides estimated from RL07p V2 NEQs

- ➢ Refined VCMs for KBR/LRI observation noise based on RL07p V2 post-fit residual analysis on a monthly basis. Impact:
  - More realistic formal errors
  - Slightly reduced ocean RMS




Formal errors



# Conclusions

- The GFZ RL07 GRACE/GRACE-FO Level-2 products will include a reduced noise level and more realistic formal errors, compared to RL06

- New components for the RL07 processing strategy
  - Stochastic modeling of instrument errors (ll-SST/ACC & GPS)
  - Stochastic modeling of AO background model errors
  - Optimal weighting of ll-SST and GPS by means of VCE

- For GRACE-FO, a release of LRI-based fields is planned as well

- Publication of RL07 is planned for the end of 2025, beginning with GRACE

# References

Murböck, M., Abrykosov, P., Dahle, C., Hauk, M., Pail, R., Flechtner, F. (2023). In-Orbit Performance of the GRACE Accelerometers and Microwave Ranging Instrument. Remote Sensing 2023, 15, 563. https://doi.org/10.3390/rs15030563

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