# Towards a new release of the GOCO model: Contribution of GRACE-FO LRI data

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# GOCO25

- A combined satellite-only global gravity field model
  - Satellite gravimetry
  - Satellite Laser Ranging (SLR)
  - Kinematic orbits of Low-Earth orbit (LEO) satellites

Image credit: ESA, NASA, DLR

# GOCO25

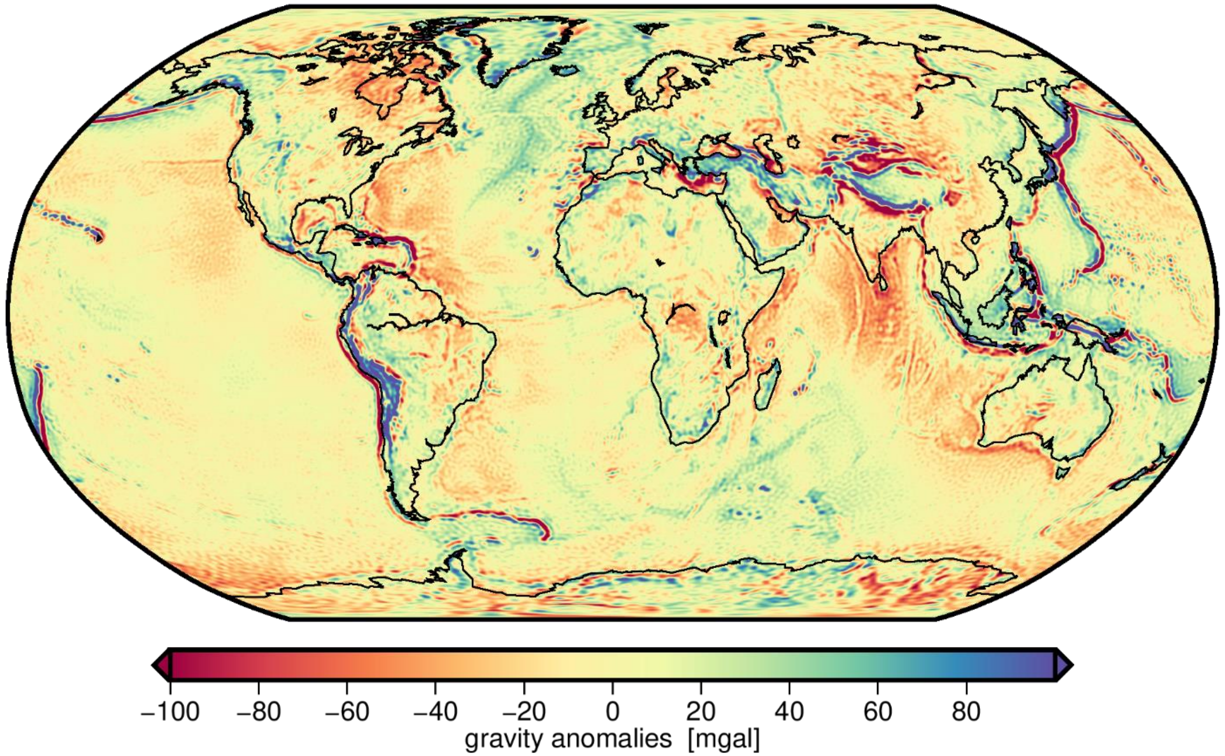
- A combined satellite-only global gravity field model
  - Satellite gravimetry
    - GRACE (2002 – 2017)
    - GOCE (2009 – 2013)
    - GRACE-FO (2018 – ongoing)
  - Satellite Laser Ranging (SLR)
    - LAGEOS 1 + LAGEOS 2
    - Ajisai
    - Stella + Starlette
    - LARES 1 + LARES 2
    - LARETS, BLITS, …
  - Kinematic orbits of Low-Earth orbit (LEO) satellites
    - GOCE
    - CHAMP
    - TerraSAR-X + TanDEM-X
    - Sentinel, Swarm, Jason, …

Image credit: ESA, NASA, DLR

# GOCO25

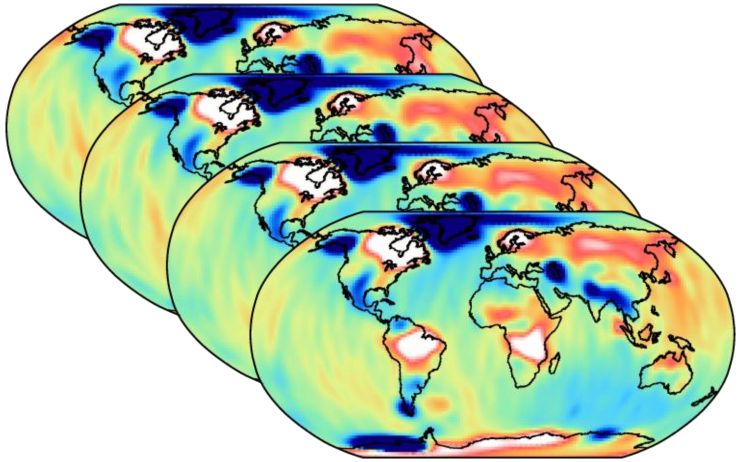
- A combined satellite-only global gravity field model
  - Static gravity field
    - Up to degree and order (d/o) 300
  - Trend
    - d/o 200
  - Annual signal
    - d/o 200
  - Semi-annual signal
    - d/o 200

→ Using over 20 years of satellite data…



# GOCO25

- Difference to GOCO06s (Kvas et al., 2021)
  - Reprocessing of the GOCE and GRACE normal equations
    - using consistent and up-to-date background models
  - Addition of the GRACE-FO normal equations
    - including LRI observations (LRI1B v54; Müller et al., 2024)
  - SLR of more satellites over a longer time span
  - Kinematic orbits of more LEO satellites



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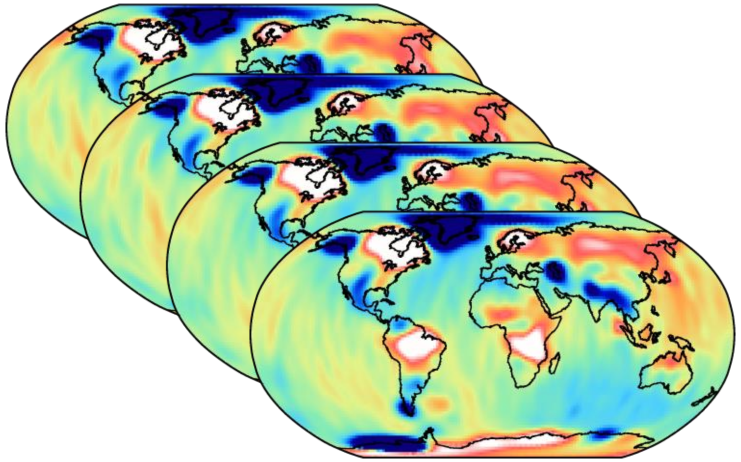
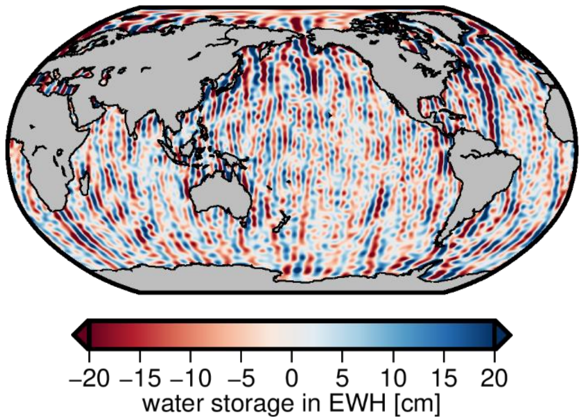


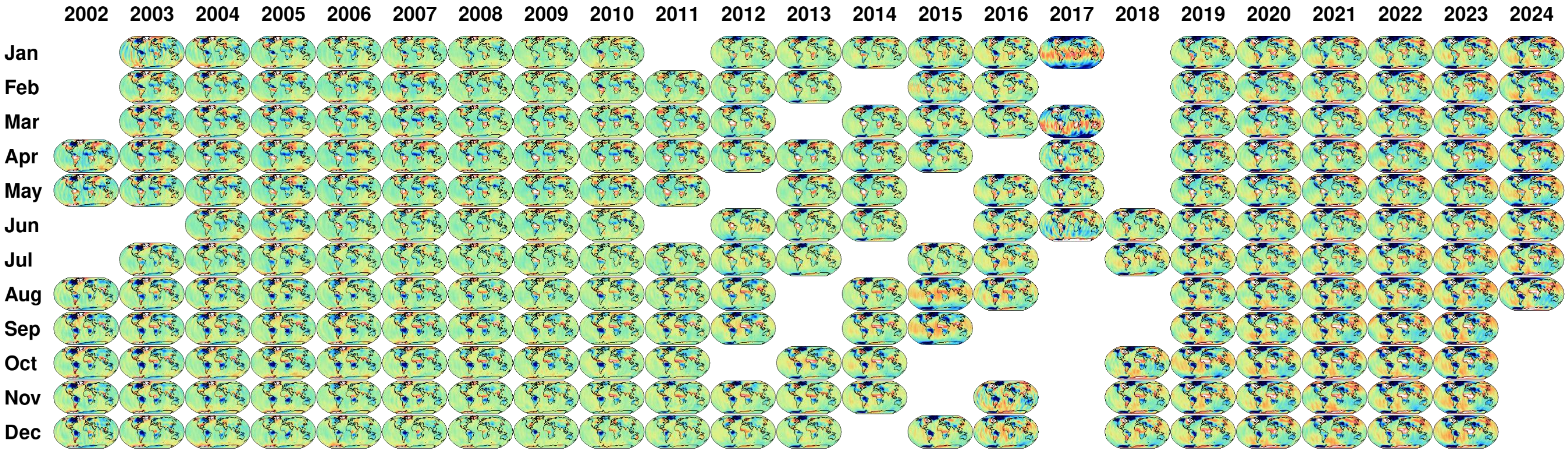
  - Re-estimation of background model uncertainties using AODRL07 (Shihora et al., 2022)
  - Ocean tides
    - new GRACE/GRACE-FO correction estimates
    - degree 3 tides (Sulzbach, et. al, 2022)
  - Additional estimation of semi-annual oscillation

AR 3 model



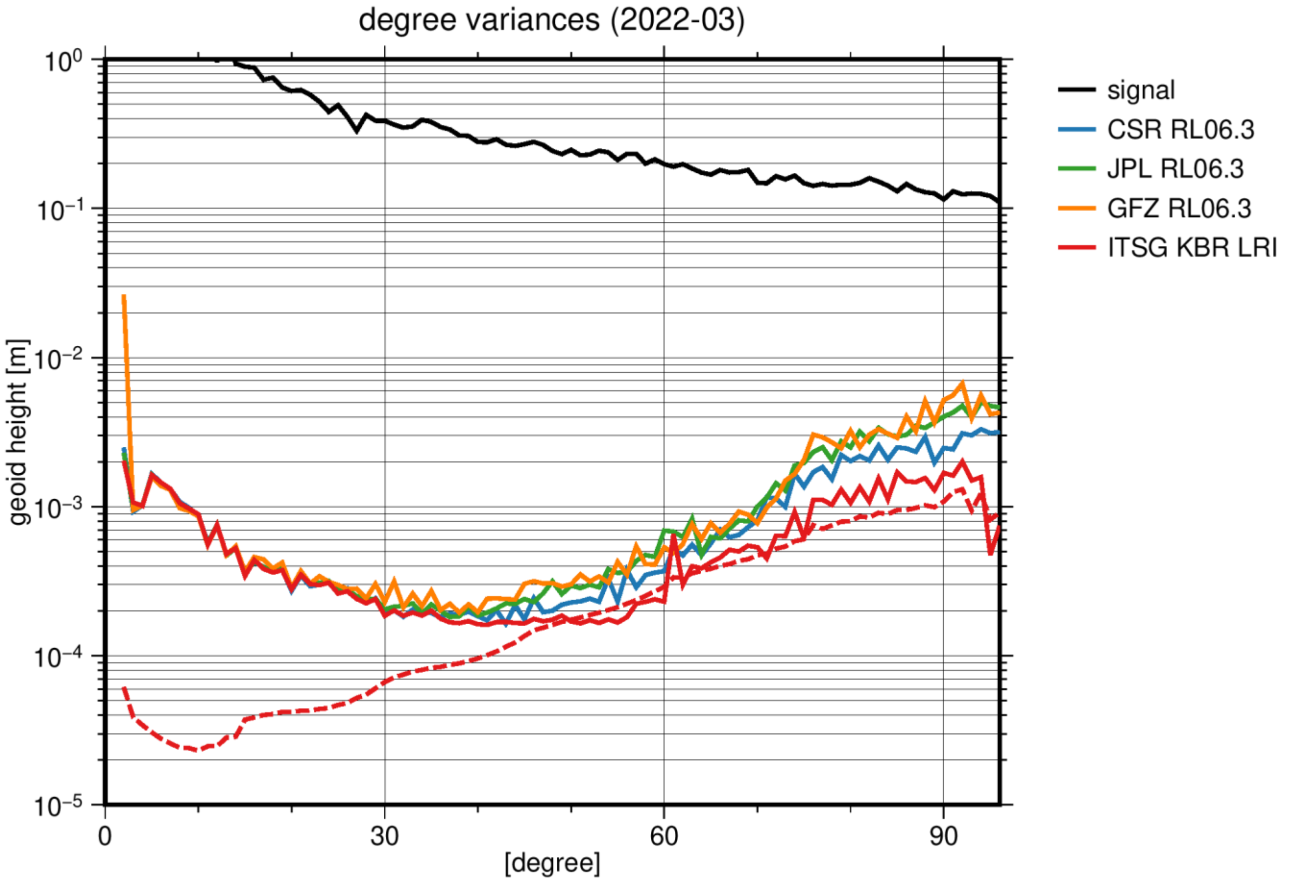
# GOCO25

- GRACE and GRACE-FO monthly solutions
  - 162 months of GRACE data
  - 73 months of GRACE-FO data so far (48 combined KBR + LRI gravity field solutions)



# Combined KBR + LRI processing: Stochastic model

- An adequate stochastic model is required:
  - to properly weigh the observations
  - to compute an optimal least-squares solution
  - to obtain realistic formal errors



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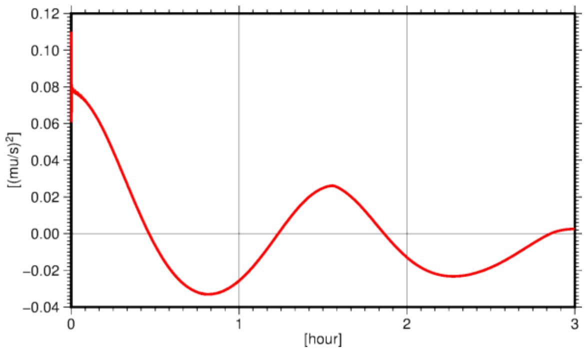
- Using both KBR and LRI measurements
  - Allows the determination of the properties of the individual noise sources (Kvas et al., 2020)
  - $\Delta l = \begin{pmatrix} l_{KBR} \\ l_{LRI} \end{pmatrix} - \begin{pmatrix} f_0 \\ f_0 \end{pmatrix}$ , $f_0 = f_m(x_0, y_m, a_{ACC}, a_{ACT}, \ldots)$
  - $f_m$ ... functional model including errors and noise of background models, accelerations, …
  - $f_0$ ... is common to both SST measurements → can be separated

# Combined KBR + LRI processing: Stochastic model

- Covariance function
  - Assumption of stationary noise for each noise component $k$: $\Sigma_{KBR}$, $\Sigma_{LRI}$, $\Sigma_{CMN}$
    - $\Sigma_{CMN}$ … covariance matrix of common noise sources
    - Covariance matrices are Toeplitz matrices
    - Setup for a short interval e.g. 3 hours



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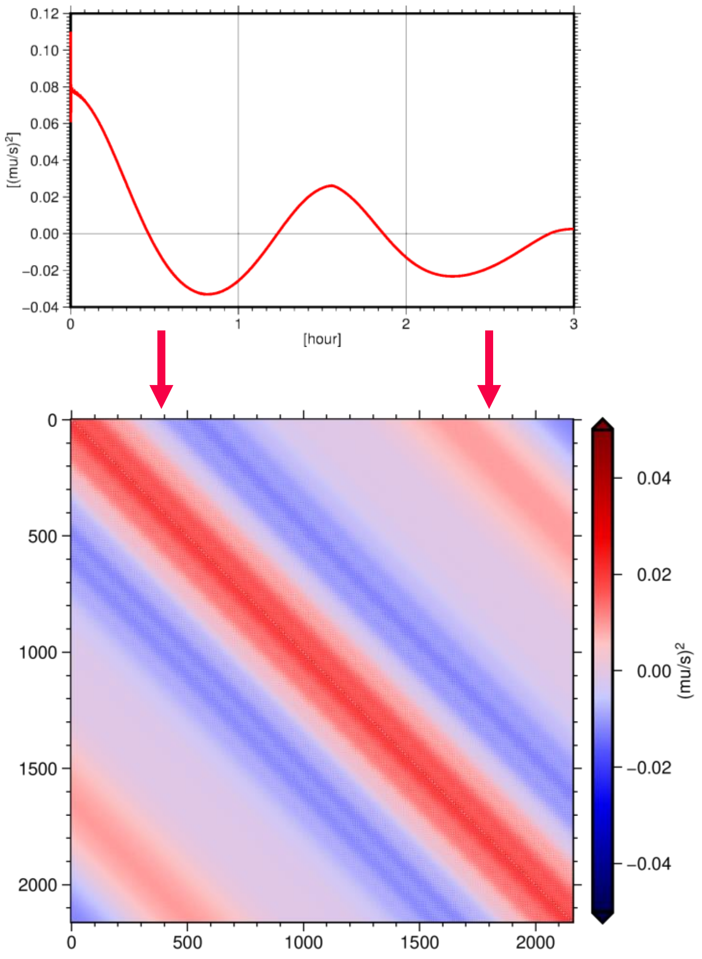
    - Setup for a short interval e.g. 3 hours
  - Expressed by the amplitudes of the power spectrum
    - $\sum_k = a_1^2 \mathrm{F}_1 + a_2^2 \mathrm{F}_2 + \cdots + a_N^2 \mathrm{F}_N$
    - $\mathrm{F}_n = \left(\cos\left(\frac{2\pi}{T} n(t_i - t_j)\right)\right)_{ij}$ … cos-transformation matrix
    - $a_n^2$ determined through variance component estimation (VCE; Ellmer, 2018)
    - Iteratively adjusting the covariance structure of each observation group $k$



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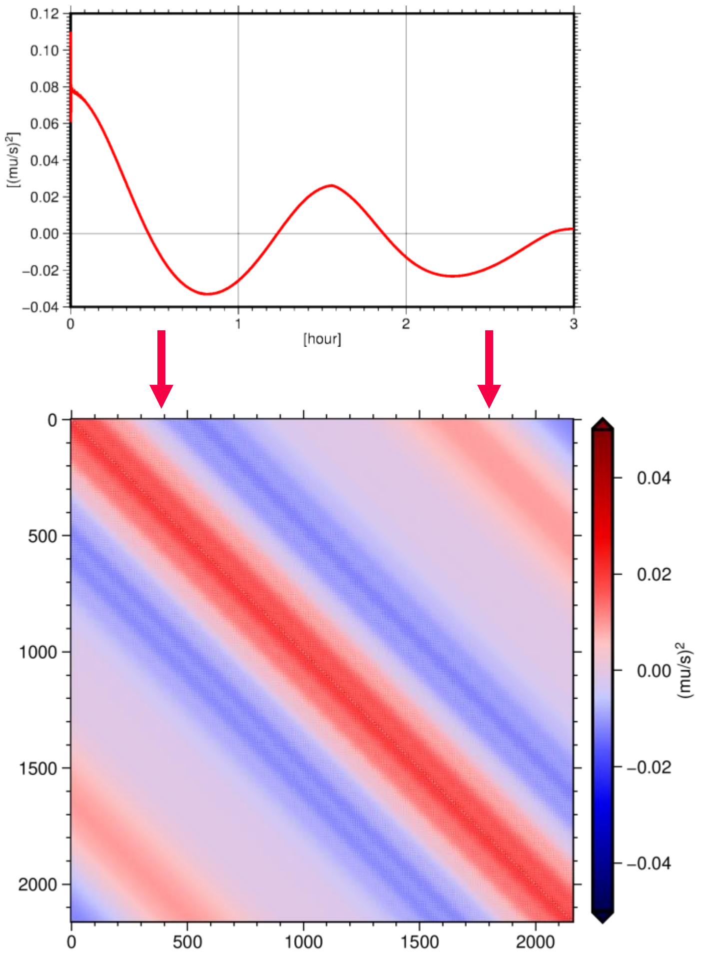
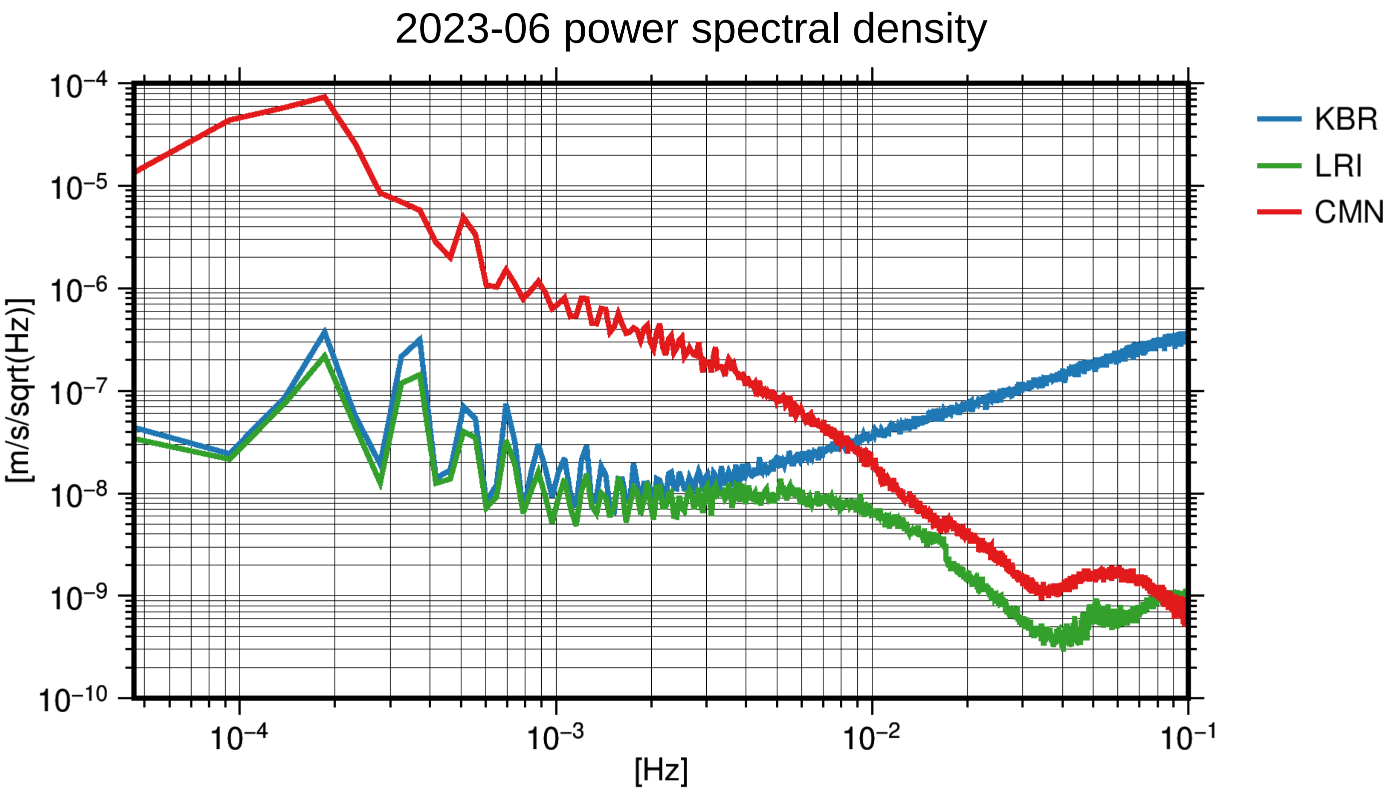
    - Iteratively adjusting the covariance structure of each observation group $k$

  - Covariance matrix of the reduced observations:
    - $\Sigma(\Delta l) = \begin{pmatrix} \Sigma_{KBR} & \\ & \Sigma_{LRI} \end{pmatrix} + \begin{pmatrix} \Sigma_{CMN} & \Sigma_{CMN} \\ \Sigma_{CMN} & \Sigma_{CMN} \end{pmatrix}$



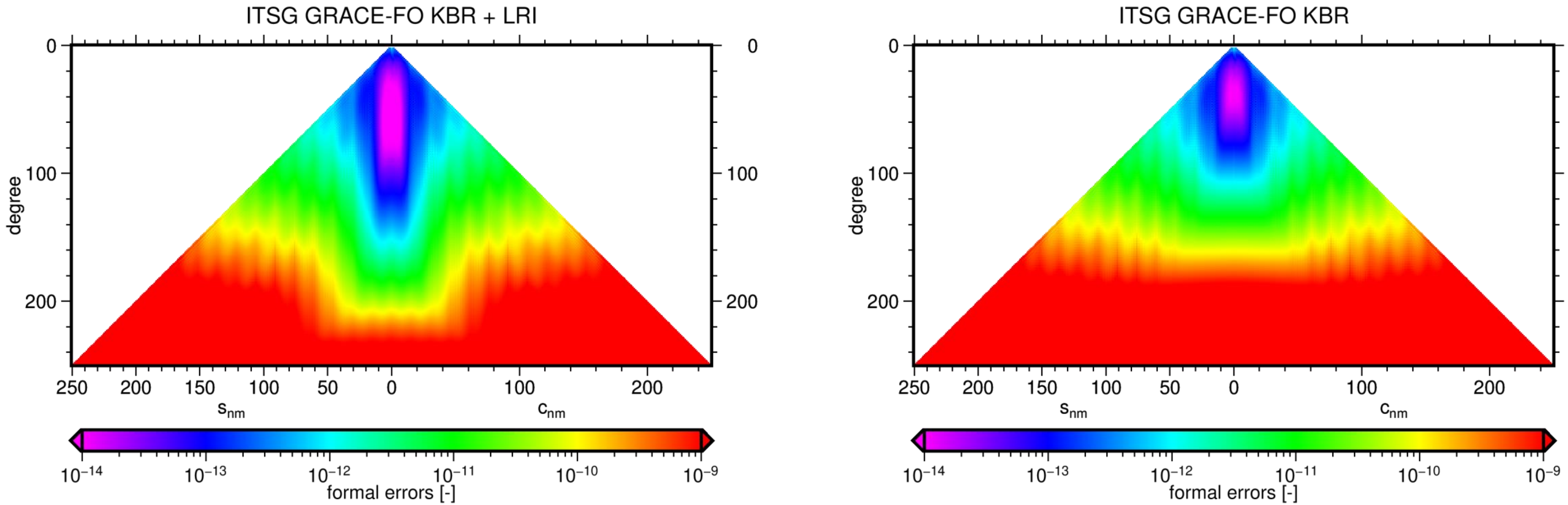
# Combined KBR + LRI processing: Disentanglement of residuals

- Partial disentanglement of KBR, LRI and CMN residuals
  - Separated post-fit residuals can be used to closer study instrument-related effects
  - Least-squares prediction using the estimated covariance functions $\Sigma_{KBR}, \Sigma_{LRI}$ and $\Sigma_{CMN}$



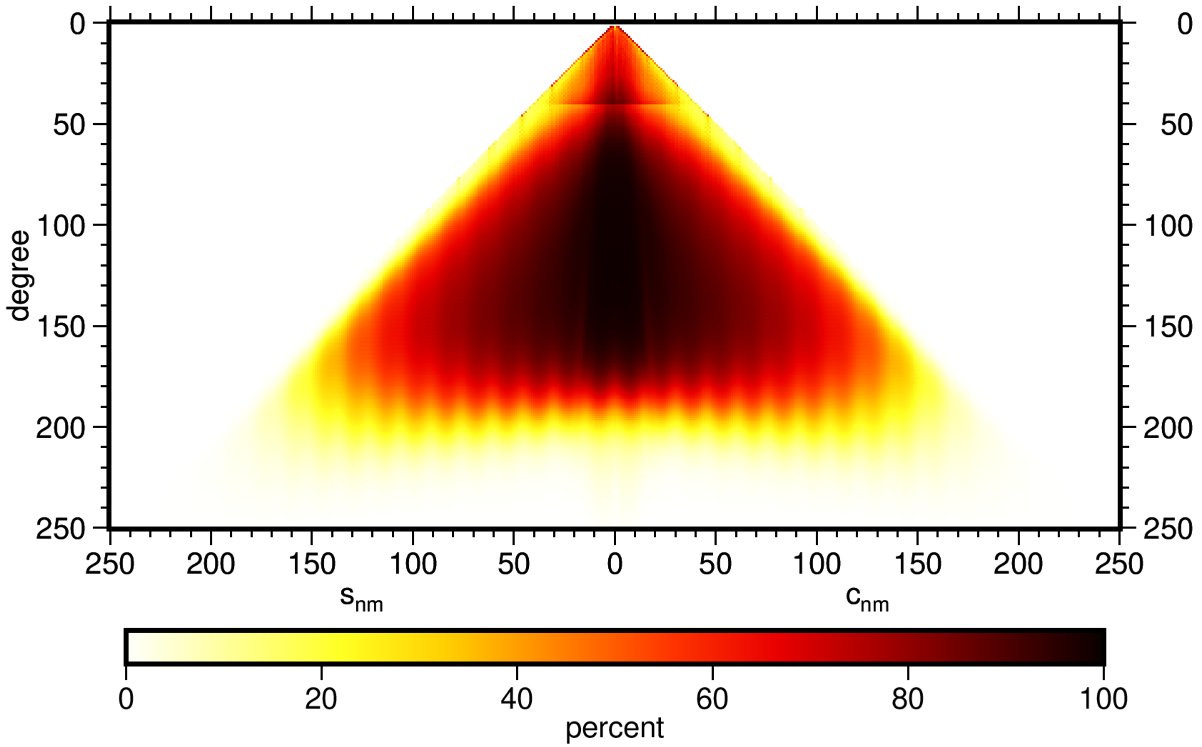
# Preliminary results

- Static gravity field
  - No estimation of trend and annual-(semiannual) oscillation so far
    - will be done using a regionally adapted Kaula regularization strategy (Kvas, 2021)
  - Estimated up to d/o 250 (using data from 2019-01 to 2023-06)
    - Comparison of KBR + LRI and KBR-only solution
    - Improvement due to inclusion of LRI data



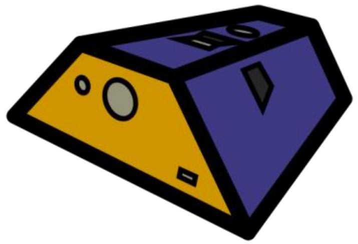
# Preliminary results

- Static gravity field
  - Combination of GOCO06s and GRACE-FO KBR + LRI solution
    - Contribution of LRI observations:
      - biggest impact at near-zonal coefficients up to d/o 200



# Processing software

- GROOPS
  - Source code available on GitHub: https://github.com/groops-devs/groops
  - Documentation and Cookbook: https://groops-devs.github.io/groops/html/index.html
  - Corresponding paper: Mayer-Gürr et al. (2021) https://doi.org/10.1016/j.cageo.2021.104864



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