Time-variable gravity field determination from GRACE Follow-On data at the AIUB

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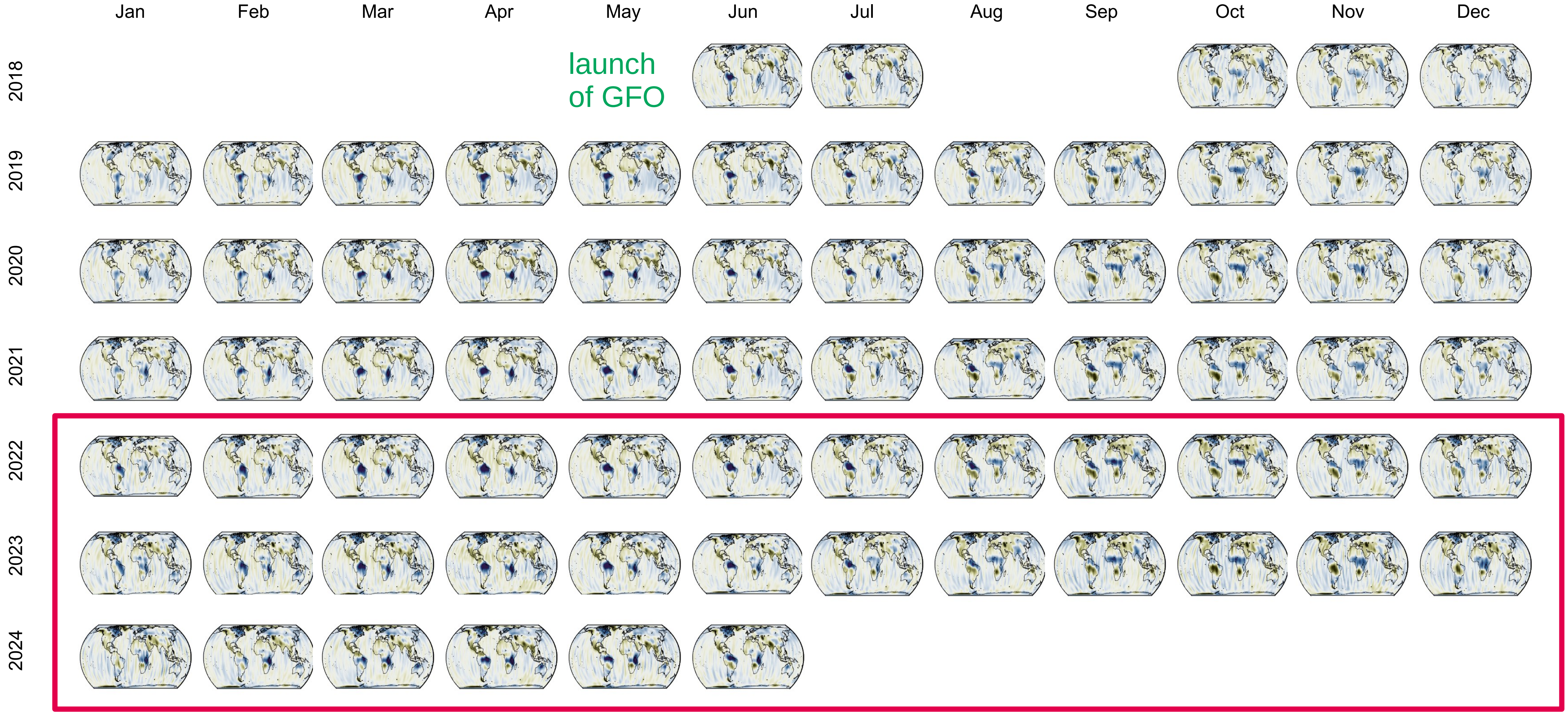
GRACE Follow-On Science Team Meeting 2024, 8 – 10 October 2024, Potsdam, Germany

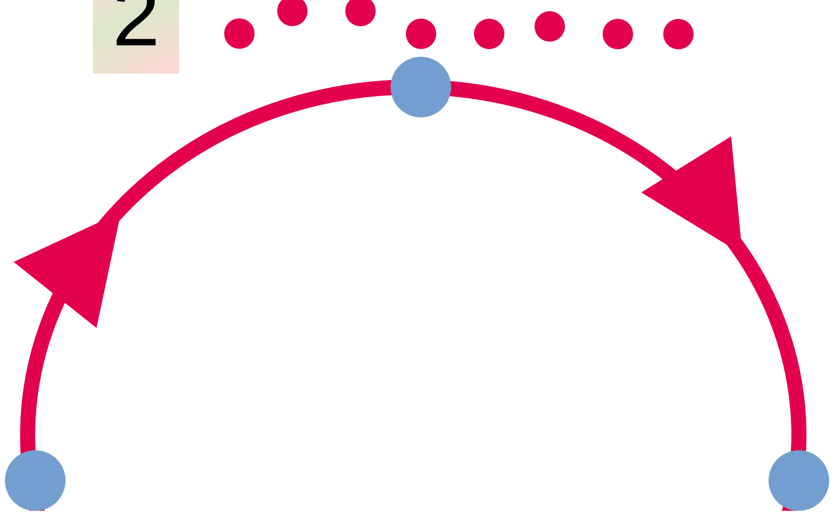
Operational GRACE Follow-On Solution

Mosaic Jun 2018 – Jun 2024



Gravity Field Recovery
A little detour

2 Estimate kinematic positions



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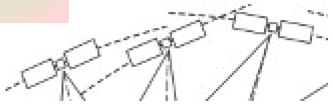
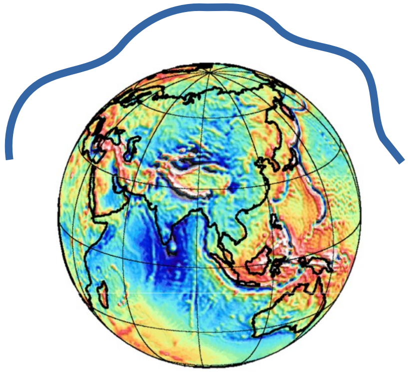


GPS observations

3

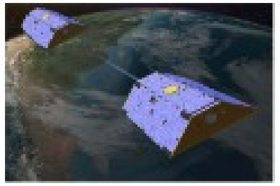
Take kinematic positions and KBR/LRI observations and estimate (reduced) dynamic orbit + gravity field

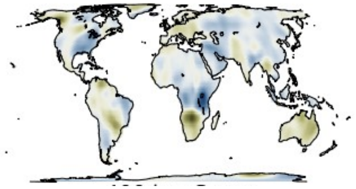


Background information
- Celestial Mechanics Approach (CMA, Beutler et al., 2010) applied
- CODE GNSS products
- PCV maps used
- Ambiguities integer-fixed

Parametrisation

For estimating gravity fields





Basic parametrisation
- Initial conditions
- Bias in radial, along-track, cross-track
- ACC scaling factors
- Off-diagonal elements for ACC scaling
  → since 2023 and for this study

Additional parameters
- 15 min PCA per satellite in
  - ➔ radial
  - ➔ along-track
  - ➔ cross-track

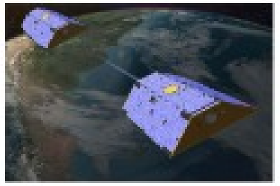
in daily arcs

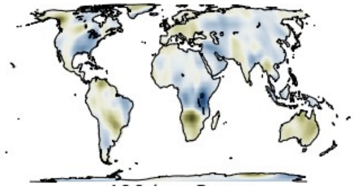
+ gravity field d/o=2..96

Σ for 30 days:
~ 18000 ‹orbit› parameters
+ 9405 gravity field d/o=2..96

Parametrisation

For estimating gravity fields





Basic parametrisation

- Initial conditions
- Bias in radial, along-track, cross-track
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- Off-diagonal elements for ACC scaling

Additional parameters

- 15 min PCA per satellite in
  - → radial
  - → along-track
  - → cross-track

+ gravity field

Force models	
Gravity field	AIUB_APR
Astronomic bodies	JPL DE421 (all planets)
Mean pole	Linear
Solid Earth tides	IERS2010
Solid Earth pole tides	IERS2010
Ocean tides	FES2014b (+ admittances from TUG)
Ocean pole tides	Desai
Atmospheric tides	AOD RL06
Atmospheric & oeanic dealiasing	AOD RL06
Relativistic effects	IERS2010

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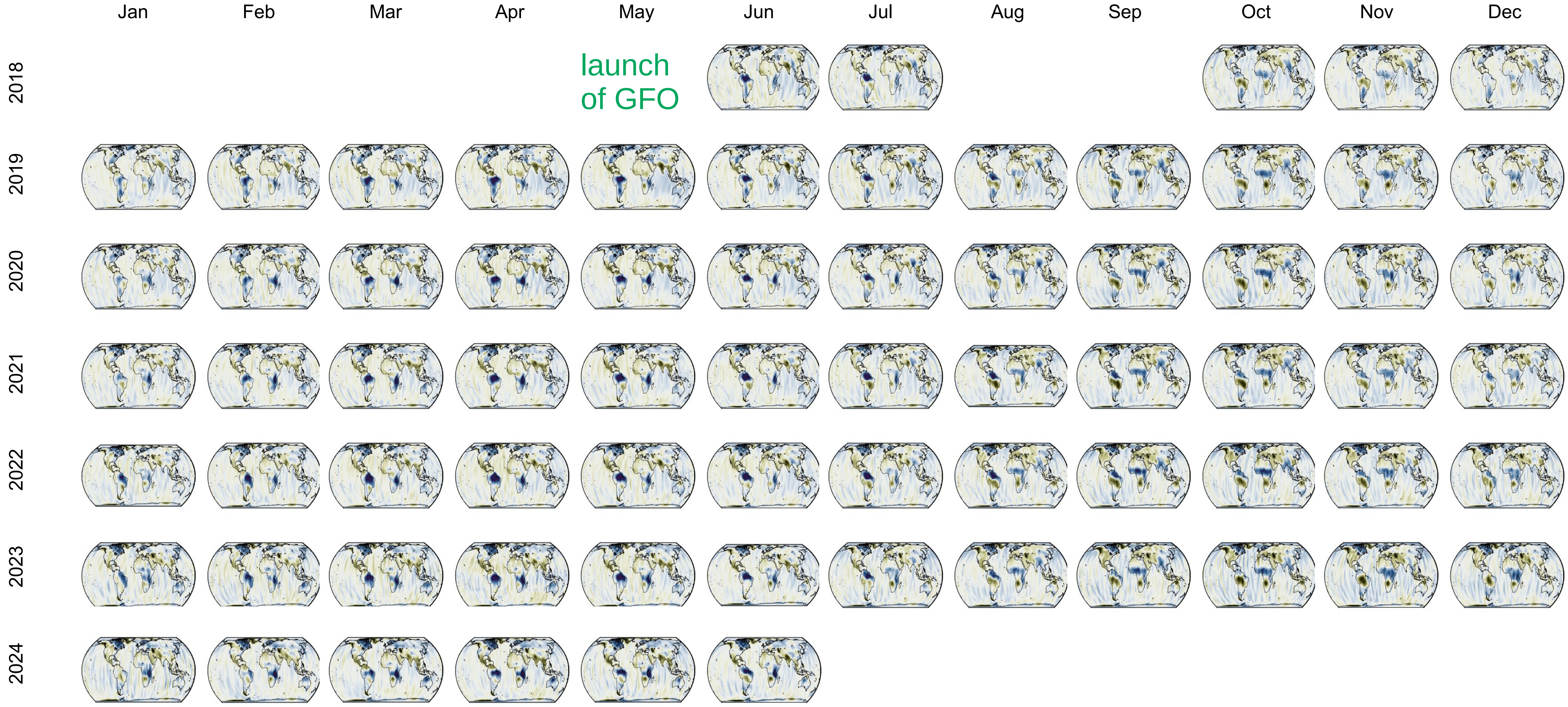
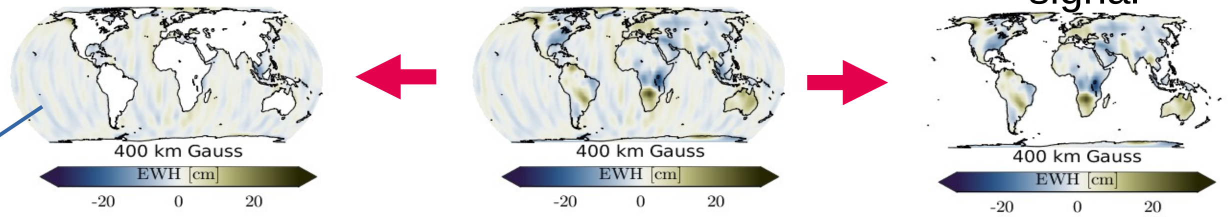


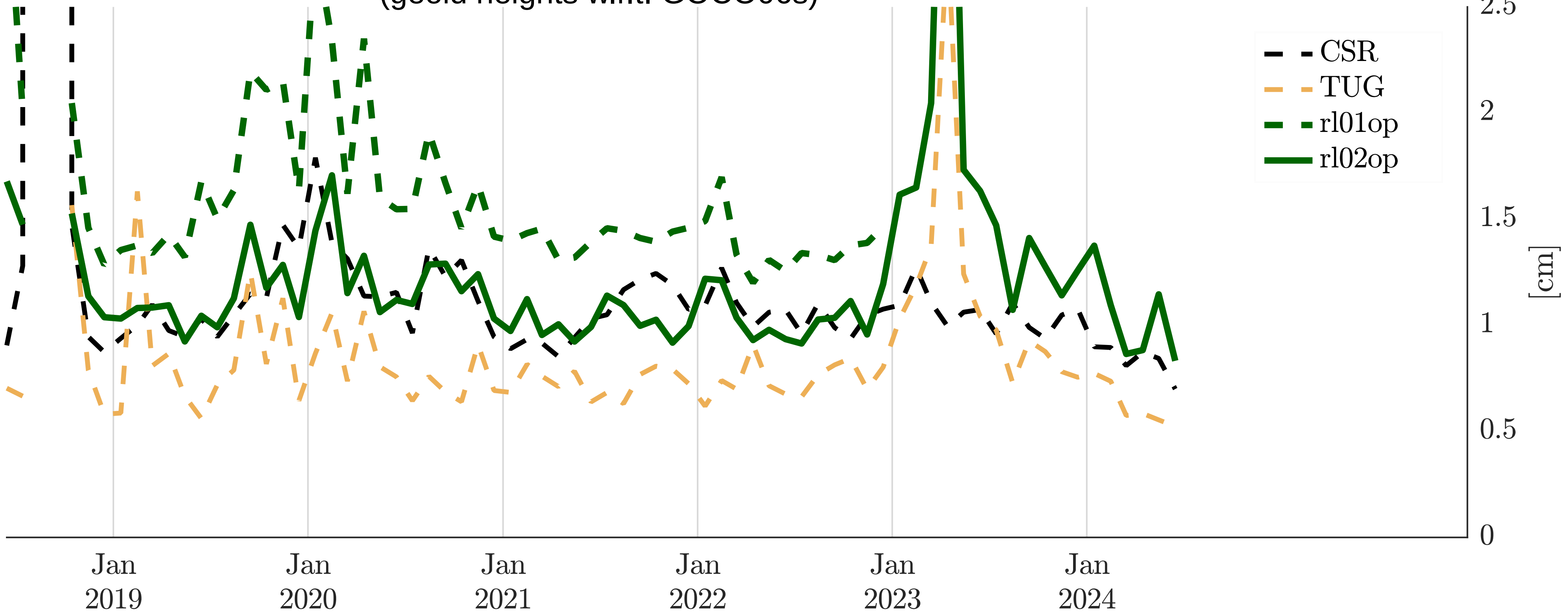
AIUB GRACE Follow-On Solutions

RMS over oceans

signal

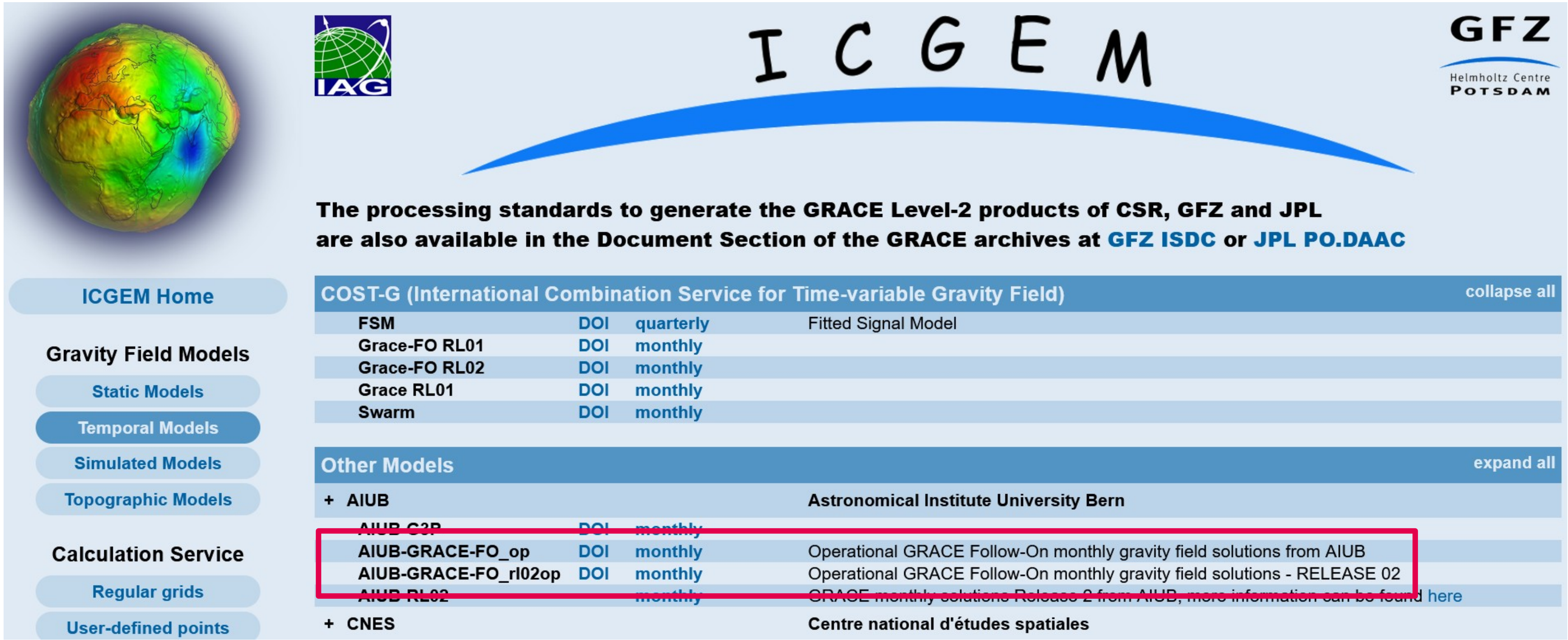


RMS over the oceans
(geoid heights w.r.t. GOCO06s)



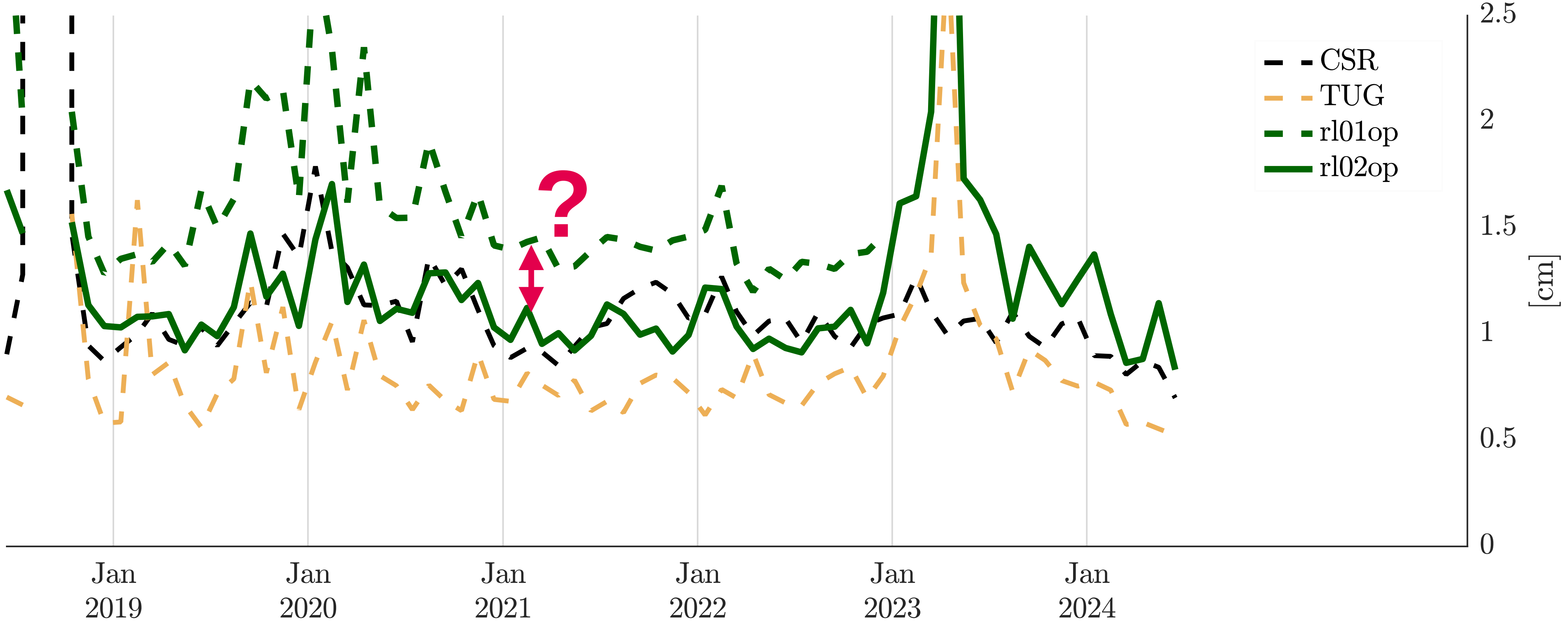
GRACE Follow-On

Observation concept



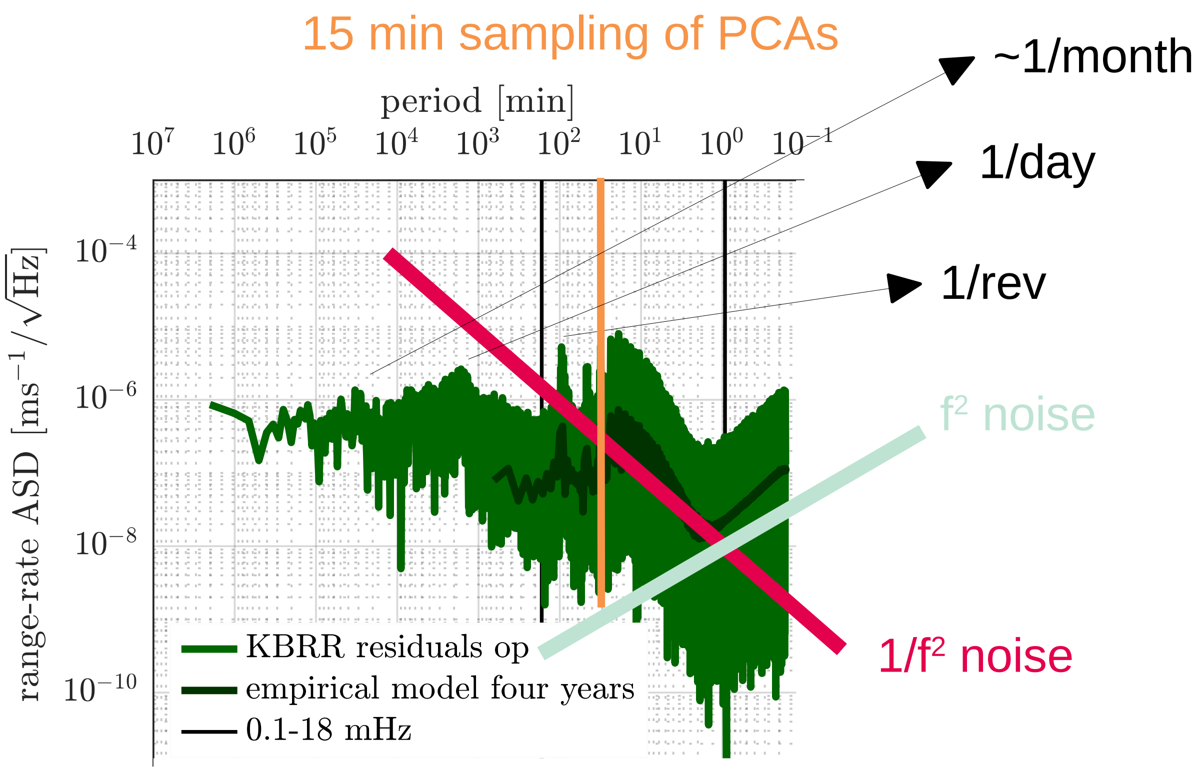
AIUB GRACE Follow-On Solutions

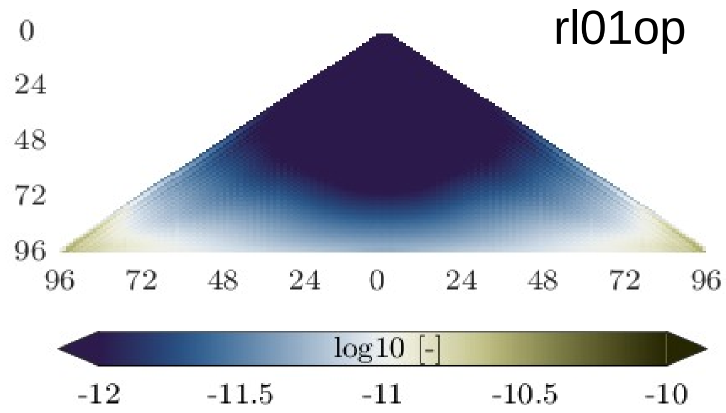
RMS over oceans



Noise modelling

Based on post-fit residuals



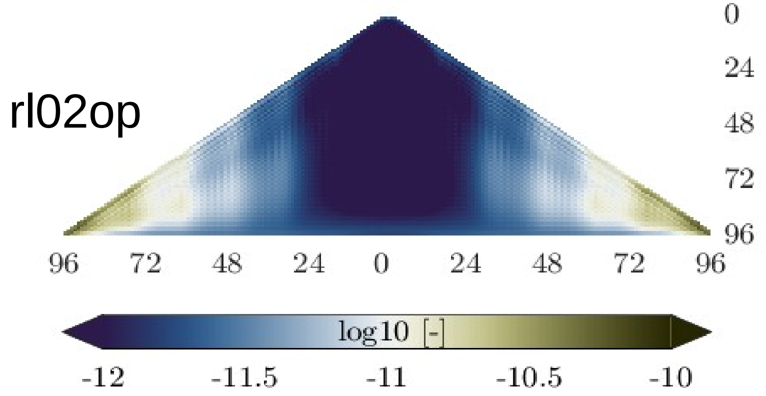


initial solution → residuals

auto covariance function →

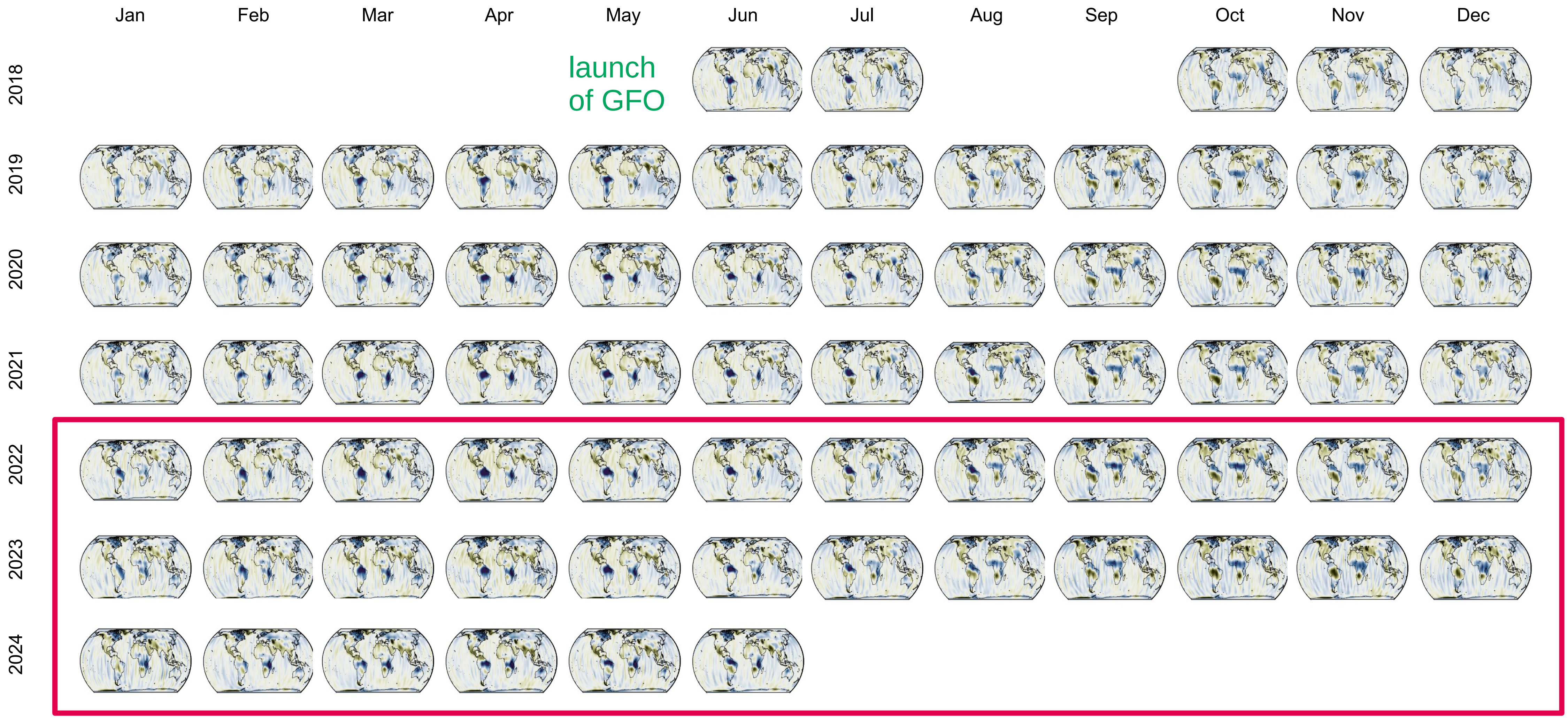
covariance matrix →

weight matrix → new estimation



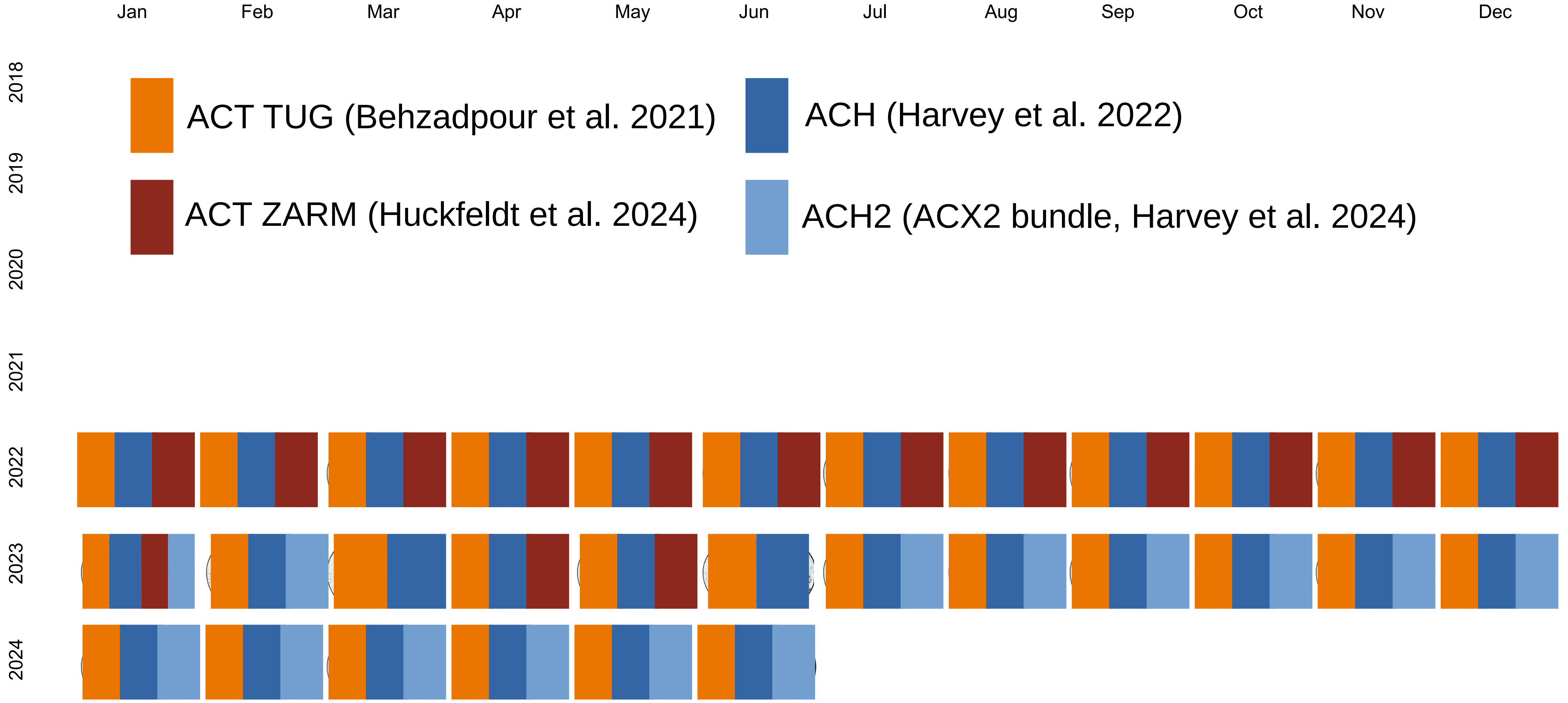
GF2 ACC products

Mosaic Jun 2018 – Jun 2024



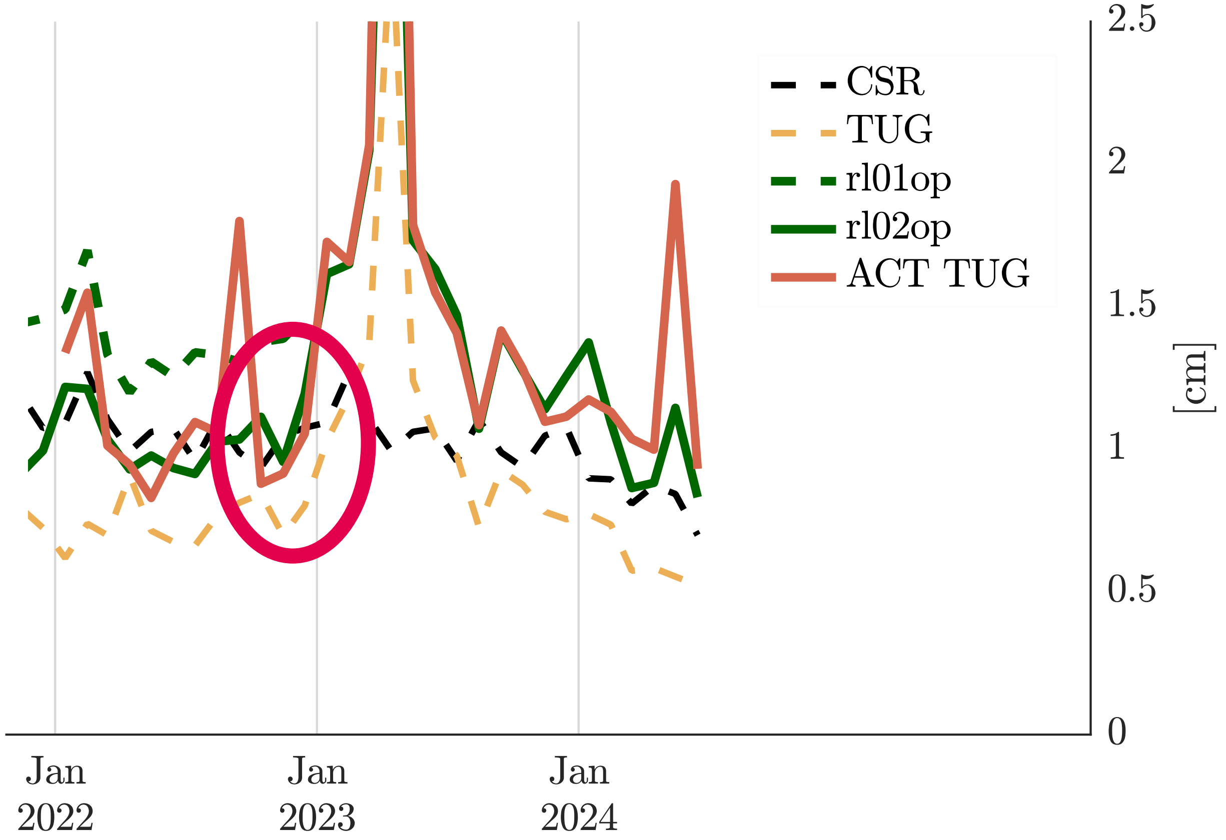
GF2 ACC products

Mosaic Jun 2018 – Jun 2024



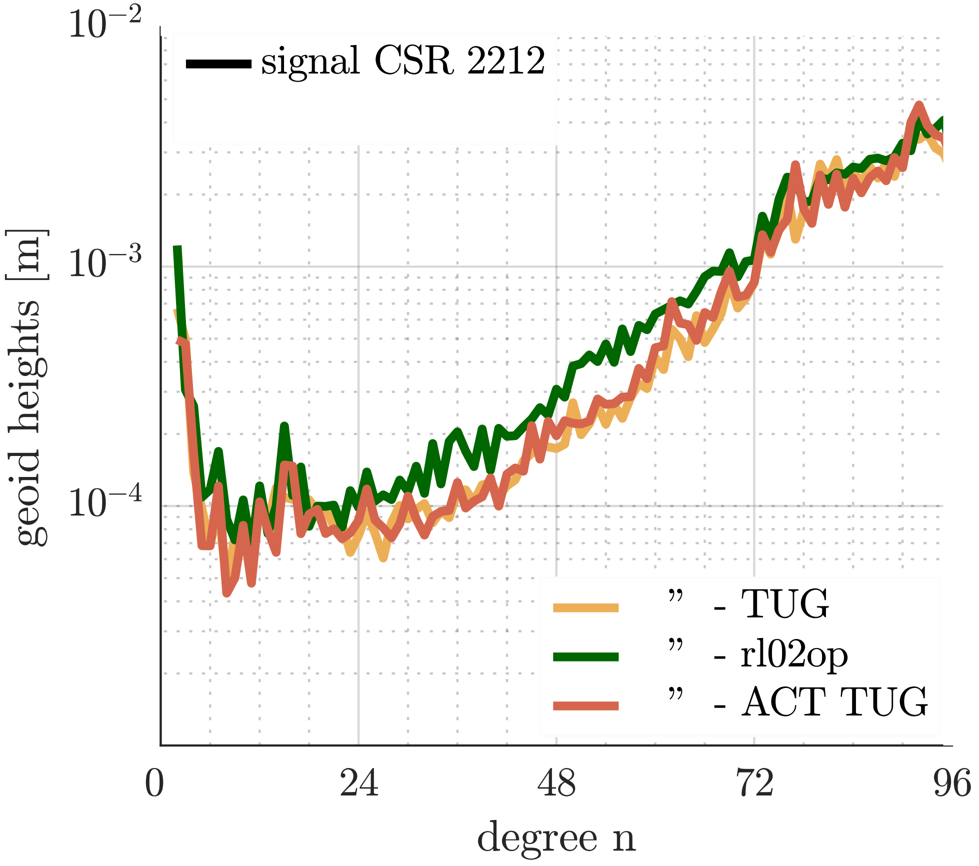
AIUB GRACE Follow-On Solutions

RMS over oceans



December 2022

Difference degree amplitudes



- Reason for the improvement: Application of variance component estimation to estimate the variance of the PCAs.

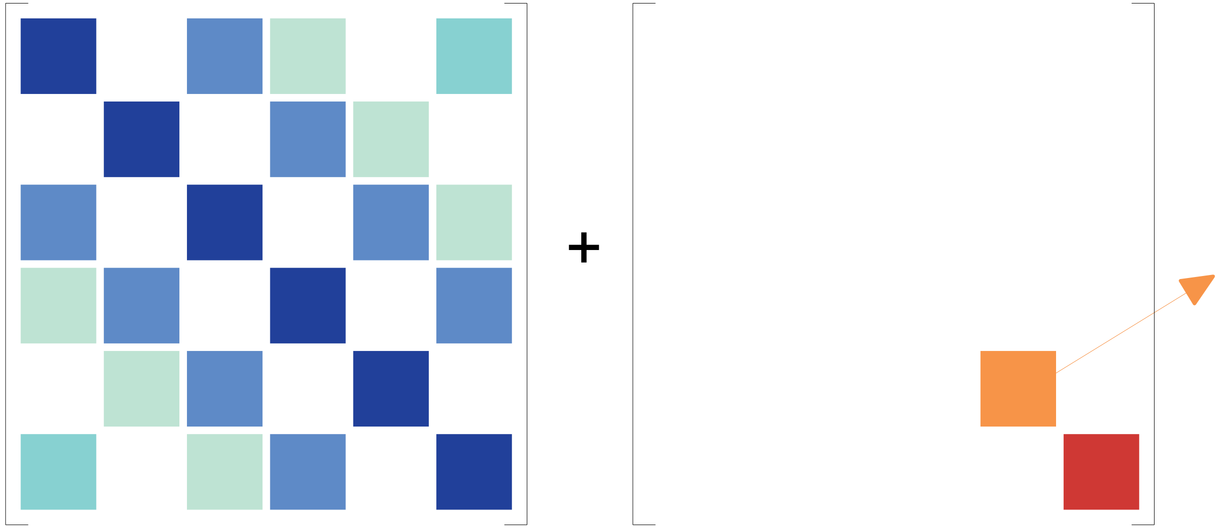
Piece-wise constant accelerations

Constraining

$$\mathbf{N} = \left(\mathbf{A}^T \mathbf{P} \mathbf{A}\right) \quad \text{and} \quad \boldsymbol{b} = \mathbf{A}^T \mathbf{P} \boldsymbol{l} \longrightarrow \hat{\boldsymbol{x}} = \mathbf{N}^{-1} \boldsymbol{b}$$

$$\mathbf{N} = \left(\mathbf{A}^T \mathbf{P} \mathbf{A} + \mathbf{W}\right)$$

$N =$



$$\frac{\sigma_0^2}{\sigma_{PCA}^2},$$

$\sigma_{PCA}^2 =$ e.g., $3 \times 10^{-10}\ \mathrm{ms}^{-2}$

A design matrix

P weight matrix

$\boldsymbol{l}$ obser-vations

Piece-wise constant accelerations

Constraining

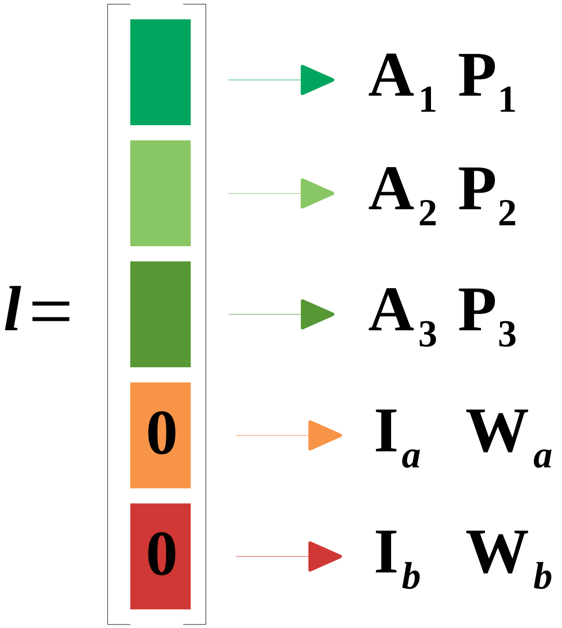
$$\mathbf{N} = \left(\mathbf{A}^T \mathbf{P} \mathbf{A}\right) \quad \text{and} \quad \boldsymbol{b} = \mathbf{A}^T \mathbf{P} \boldsymbol{l} \quad \rightarrow \quad \hat{\boldsymbol{x}} = \mathbf{N}^{-1} \boldsymbol{b}$$

$$\mathbf{N} = \left(\mathbf{A}^T \mathbf{P} \mathbf{A} + \mathbf{W}\right)$$

$\mathbf{A}$ design matrix

$\mathbf{P}$ weight matrix

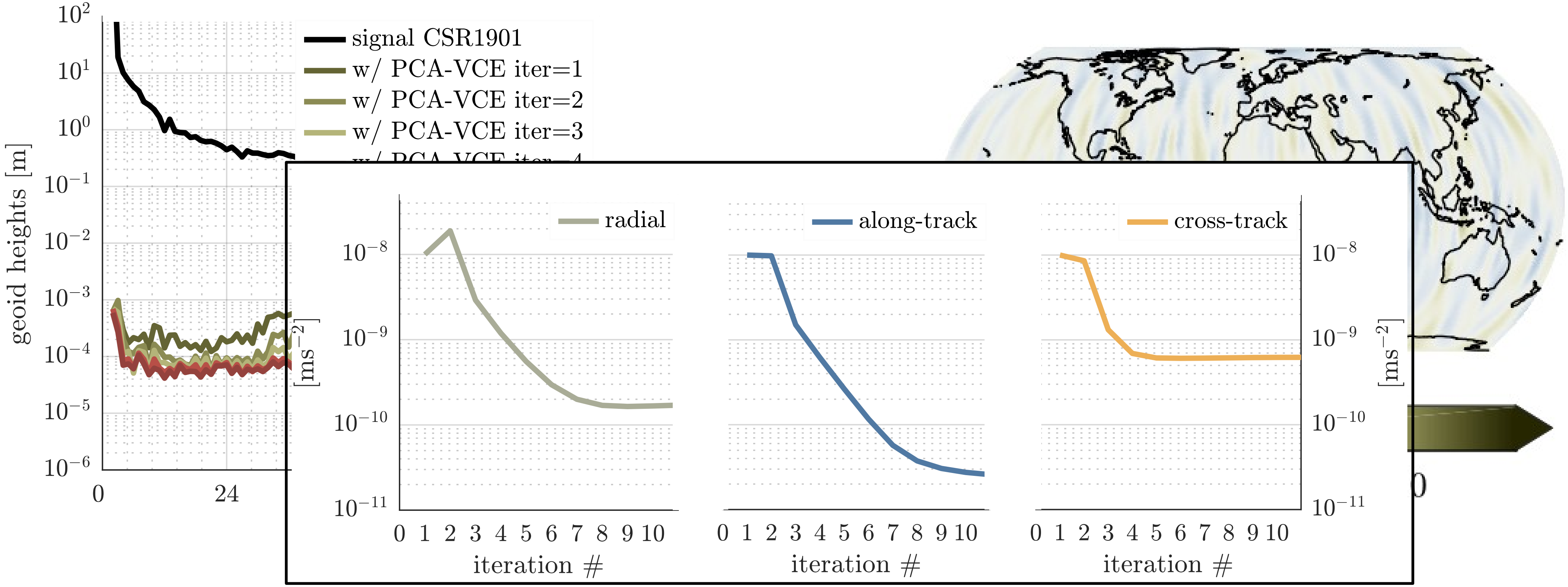
$\boldsymbol{l}$ obser-vations



- The observations of each arc are used to set up the normal equations (NEQs)
- Each arc is treated as being independent

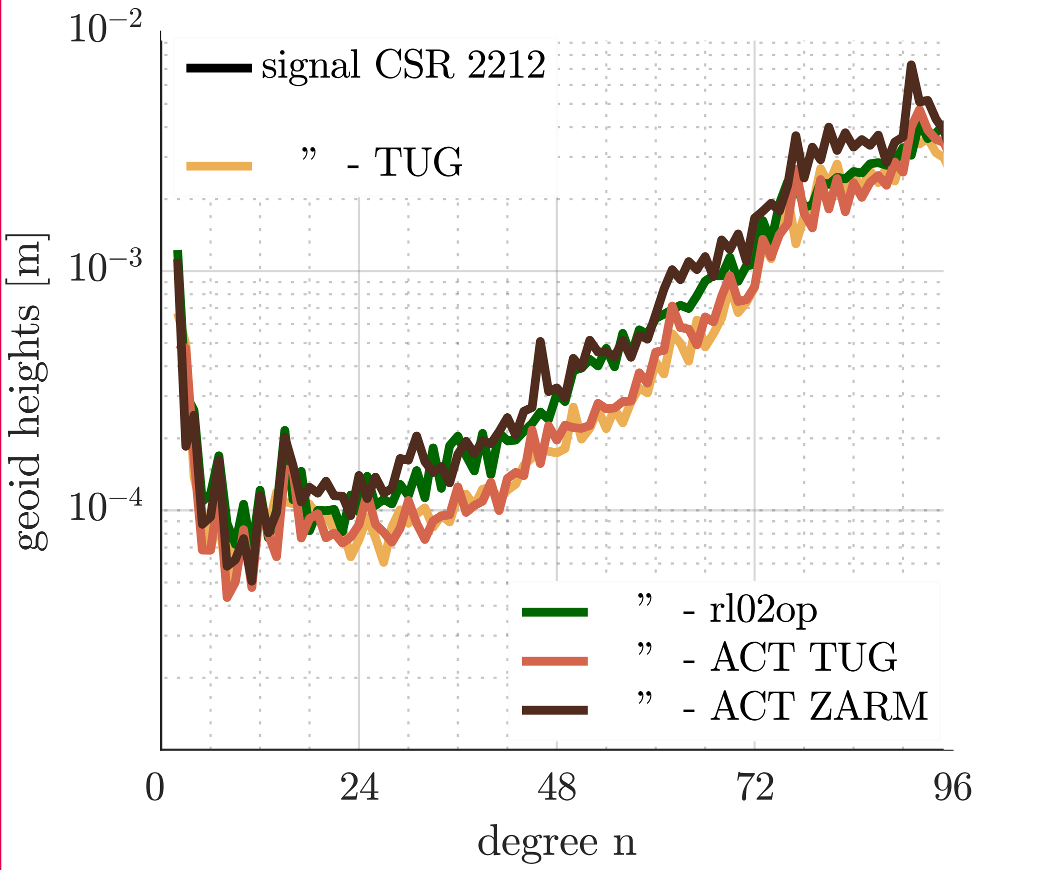
VCE: Each group of observations gets a weight based on its contribution to the final solution

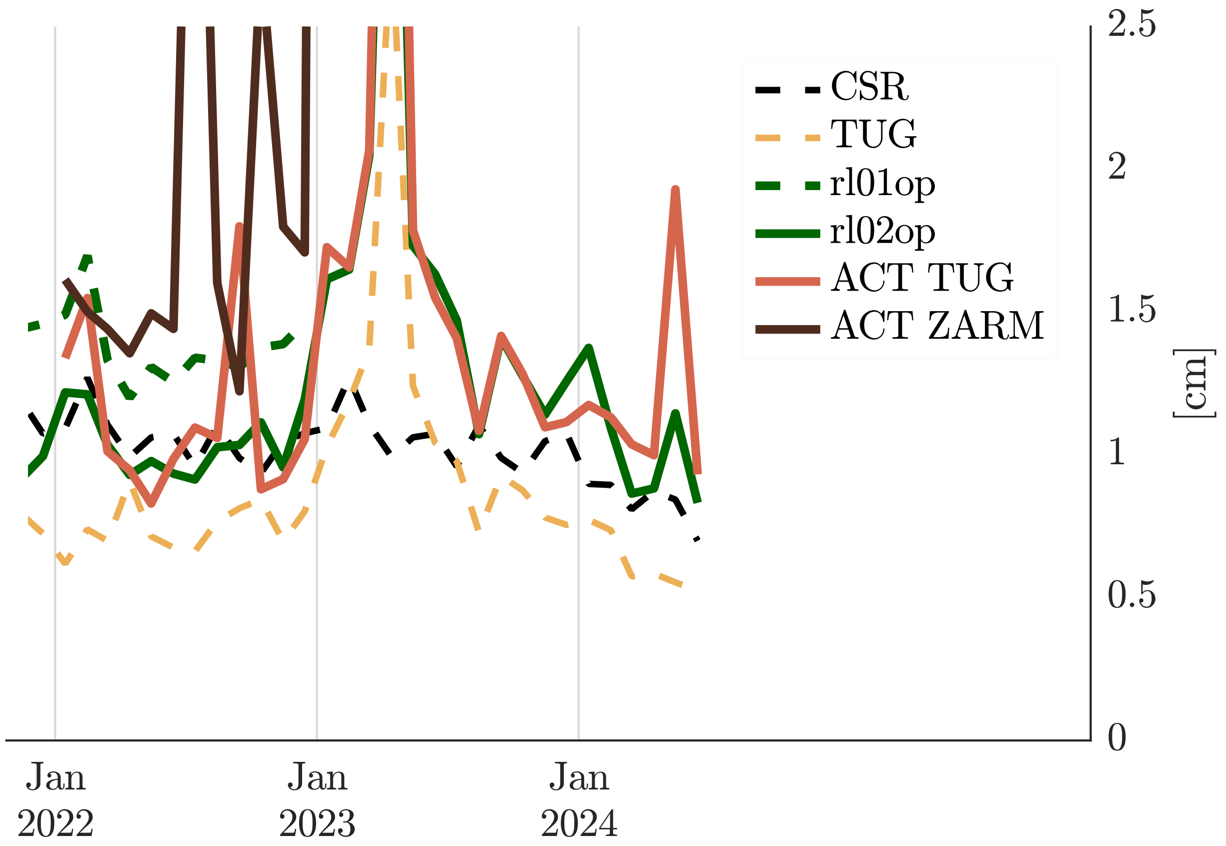
Piece-wise constant accelerations
Constraining



AIUB GRACE Follow-On Solutions

RMS over oceans

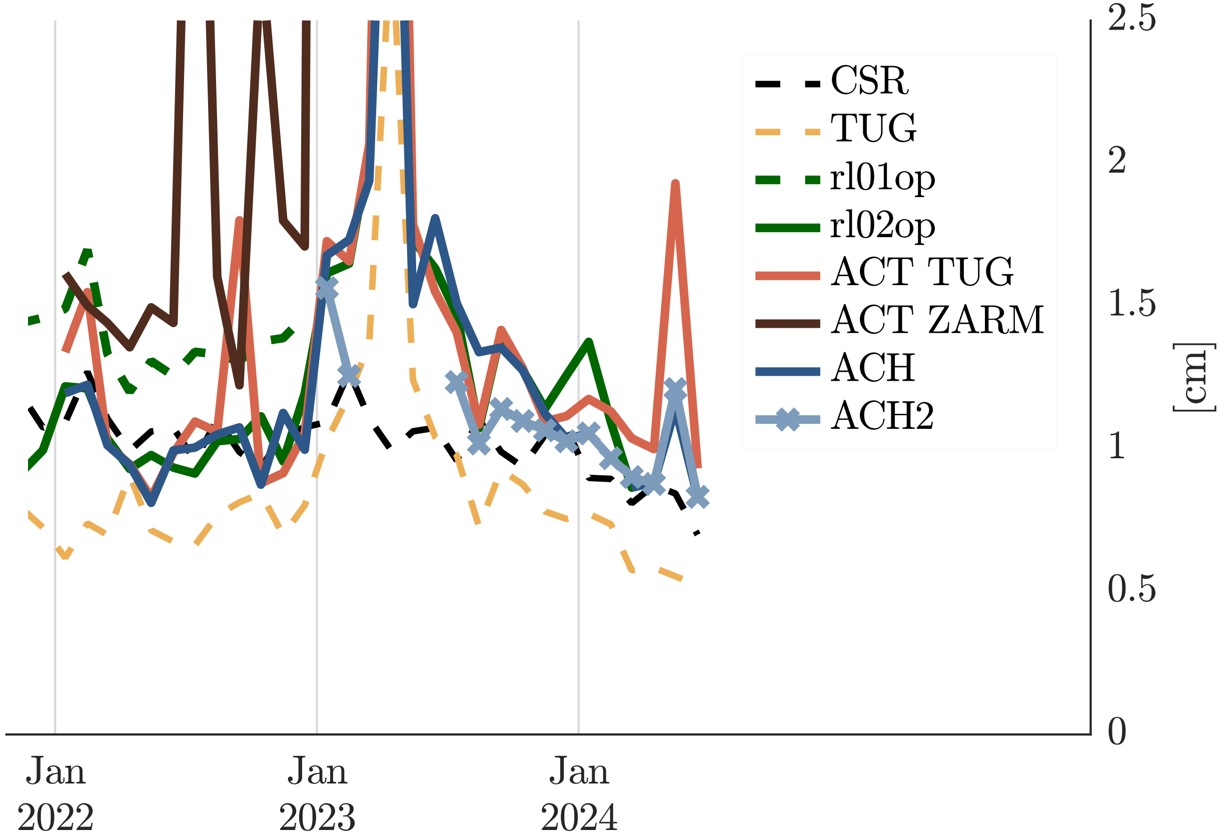




AIUB GRACE Follow-On Solutions

RMS over oceans

- ACH → JPL's hybrid transplant
- ACH2 → ACH from ACX2 bundle

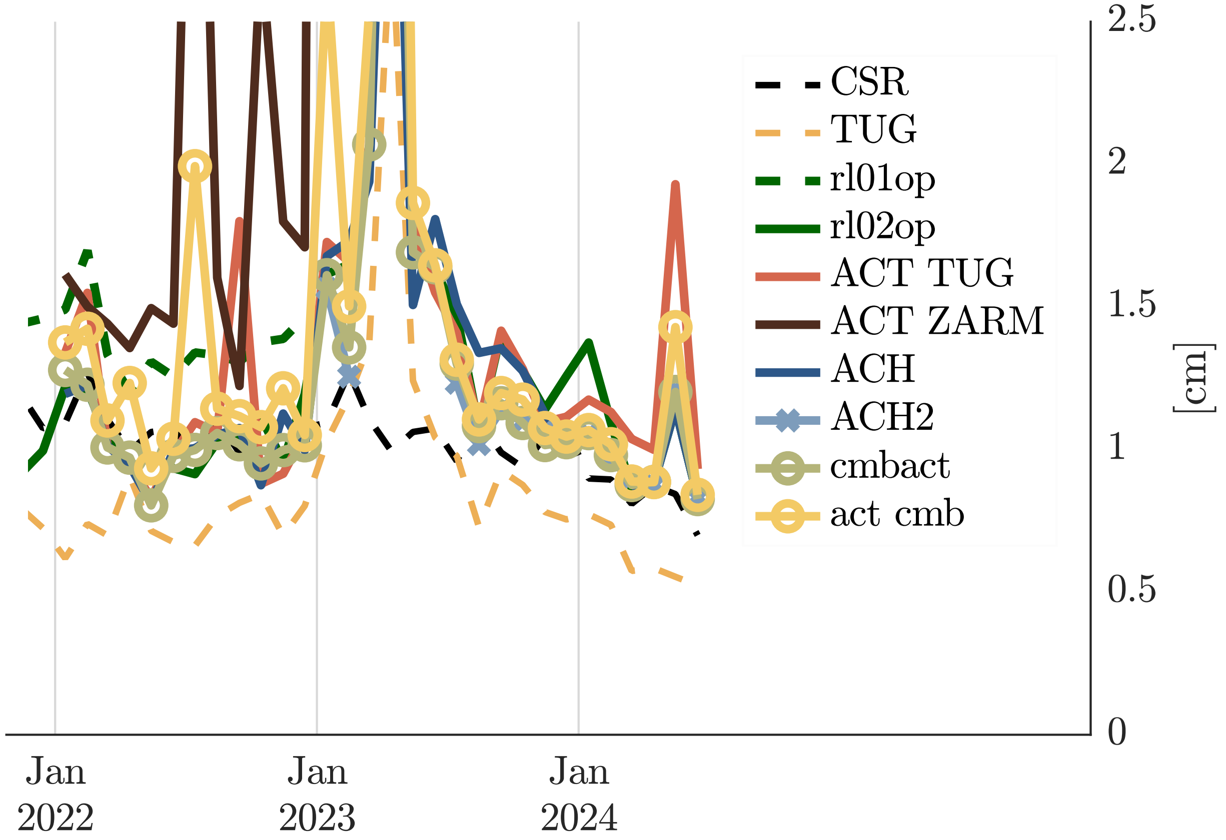


GF2 – four ACT products

What to do?

Scenario #1 (cmbact)
Combine ACT products on NEQ level

Scenario #2 (act cmb)
Combine ACT products by simple average



Summary
& Conclusions

- Operational solution (rl02op) up to date (most recent for Jun 2024).
- Estimation of variance components for PCAs more important with more challenging data.

- ACH2 (ACX2) improves results (most until Nov 2023).

- Simple ACT product combinations seem to be a reasonable starting point.

Further steps:
- Screening procedure needs an update.
- Update of background models.

Thank you for your attention

Contact

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References A

Beutler, G., Jäggi, A., Mervart, L. and Meyer, U. [2010]: The celestial mechanics approach: theoretical foundations. Journal of Geodesy, vol. 84(10), pp. 605-624. https://doi.org/10.1007/s00190-010-0401-7

Ellmer, M. [2018]: *Contributions to GRACE Gravity Field Recovery: Improvements in Dynamic Orbit Integration Stochastic Modelling of the Antenna Offset Correction, and Co-Estimation of Satellite Orientations.* PhD thesis, Graz University of Technology, In Monographic Series TU Graz, number 1, Verlag der Technischen Universität Graz, Graz, Austria. https://doi.org/10.3217/978-3-85125-646-8

Jäggi, A., Beutler, G., Meyer, U., Prange, L., Dach, R. and Mervart. L. [2012]: AIUB-GRACE02S - Status of GRACE Gravity Field Recovery using the Celestial Mechanics Approach. In S. Kenyon, M. C. Pacino, and U. Marti, editors, *International Association of Geodesy Symposia: Geodesy for Planet Earth*, volume 136, pages 161–170. Springer, Berlin-Heidelberg, Germany. ISBN 978-3-642-20337-4. https://doi.org/10.1007/978-3-642-20338-1_20

Jäggi, A., Meyer, U., Lasser, M., Jenny, B., Lopez, T., Flechtner, F., Dahle, C., Förste, C., Mayer-Gürr, T., Kvas, A., Lemoine, J.-M., Bourgogne, S., Weigelt, M. and Groh, A. [2020]: International Combination Service for Time-Variable Gravity Fields (COST-G) – Start of Operational Phase and Future Perspectives. In J. Freymueller, editor, *International Association of Geodesy Symposia*, pages 1–9, Springer Berlin-Heidelberg, Germany. https://doi.org/10.1007/1345_2020_109

References
B

Kvas, A., Brockmann, J. M., Krauss, S., Schubert, T., Gruber, T., Meyer, U., Mayer-Gürr, T., Schuh, W.-D., Jäggi, A. and Pail, R. [2021]: GOCO06s – a satellite-only global gravity field model. Earth System Science Data, 13(1):99–118. https://doi.org/10.5880/ICGEM.2019.002

Kvas, A., Behzadpour, S., Ellmer, M., Klinger, B., Strasser, S., Zehentner, N. and Mayer-Gürr, T. [2019]: Overview and evaluation of a new GRACE-only gravity field time series. Journal of Geophysical Research: Solid Earth. ISSN 2169-9313. https://doi.org/10.1029/2019JB017415

Lasser, M. [2022]: *Noise Modelling for GRACE Follow-On Observables in the Celestial Mechanics Approach*. PhD thesis, University of Bern, Bern, Switzerland. https://boristheses.unibe.ch/4127/

Lasser, M., Meyer, U., Arnold, D. and Jäggi, A. [2020]: AIUB-GRACE-FO-operational - Operational GRACE Follow-On monthly gravity field solutions. https://doi.org/10.5880/ICGEM.2020.001

NASA Jet Propulsion Laboratory (JPL) [2019]: GRACE-FO Monthly Geopotential Spherical Harmonics CSR Release 6.0. https://doi.org/10.5067/GFL20-MC060