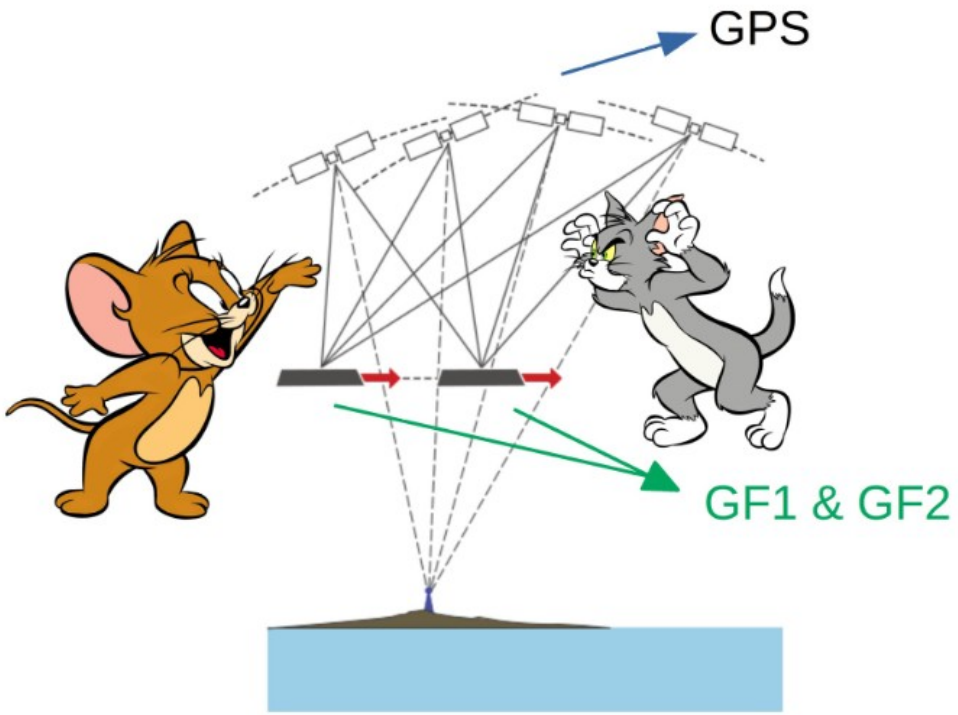
Integration of Laser Ranging Range-Rate Observations into the GRACE Follow-On Processing at the AIUB

Martin Lasser, Ulrich Meyer, Daniel Arnold and Adrian Jäggi
EGU General Assembly 2024, 14 – 19 April 2024, Vienna, Austria

Astronomical Institute University of Bern

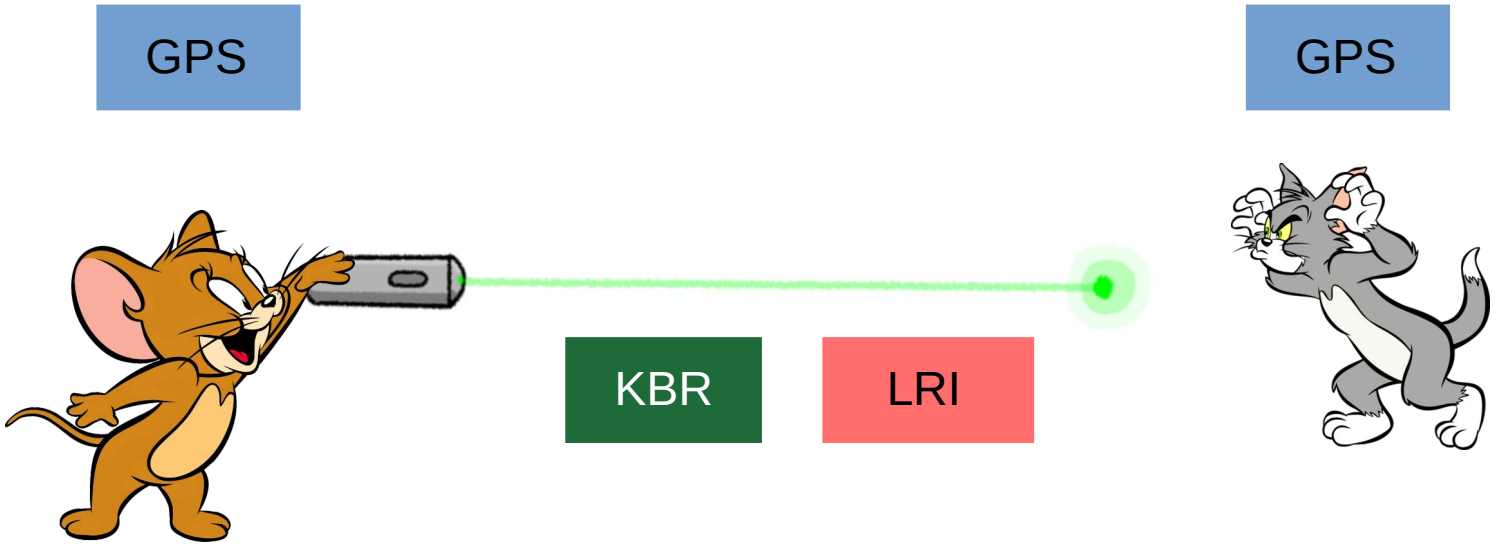
GRACE/GRACE Follow-On

Observation concept



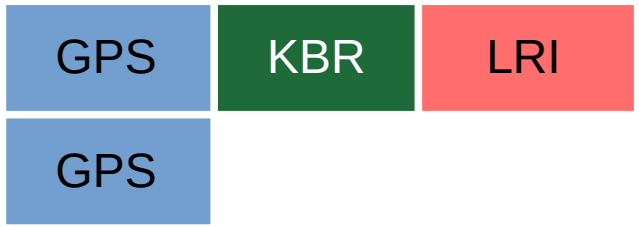
GRACE Follow-On

Observables in L2 processing



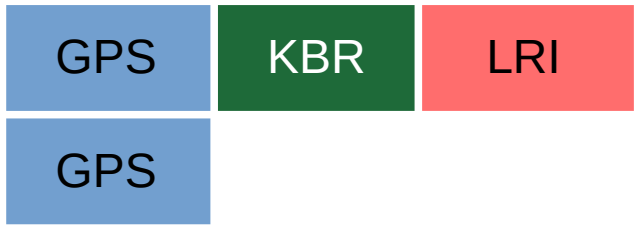
GRACE Follow-On

Observables in L2 processing

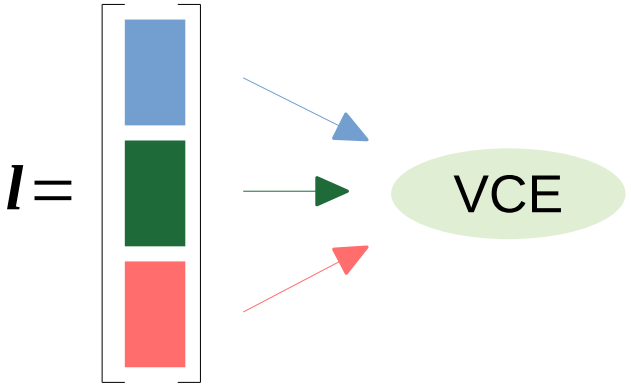


$$\boldsymbol{l} = \begin{bmatrix} \\ \\ \\ \end{bmatrix} \rightarrow \mathbf{A_1}\ \mathbf{P_1},\ \mathbf{A_2}\ \mathbf{P_2},\ \mathbf{A_3}\ \mathbf{P_3} \Bigg\} \quad \mathbf{N} = \left(\mathbf{A}^T \mathbf{P}\, \mathbf{A}\right),\ \boldsymbol{b} = \mathbf{A}^T \mathbf{P}\, \boldsymbol{l} \quad \Rightarrow \quad \hat{\boldsymbol{x}} = \left(\sum_{k=1}^{K=3} \mathbf{N}_k\right)^{-1} \sum_{k=1}^{K=3} \boldsymbol{b}_k$$

GRACE Follow-On
Observables



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

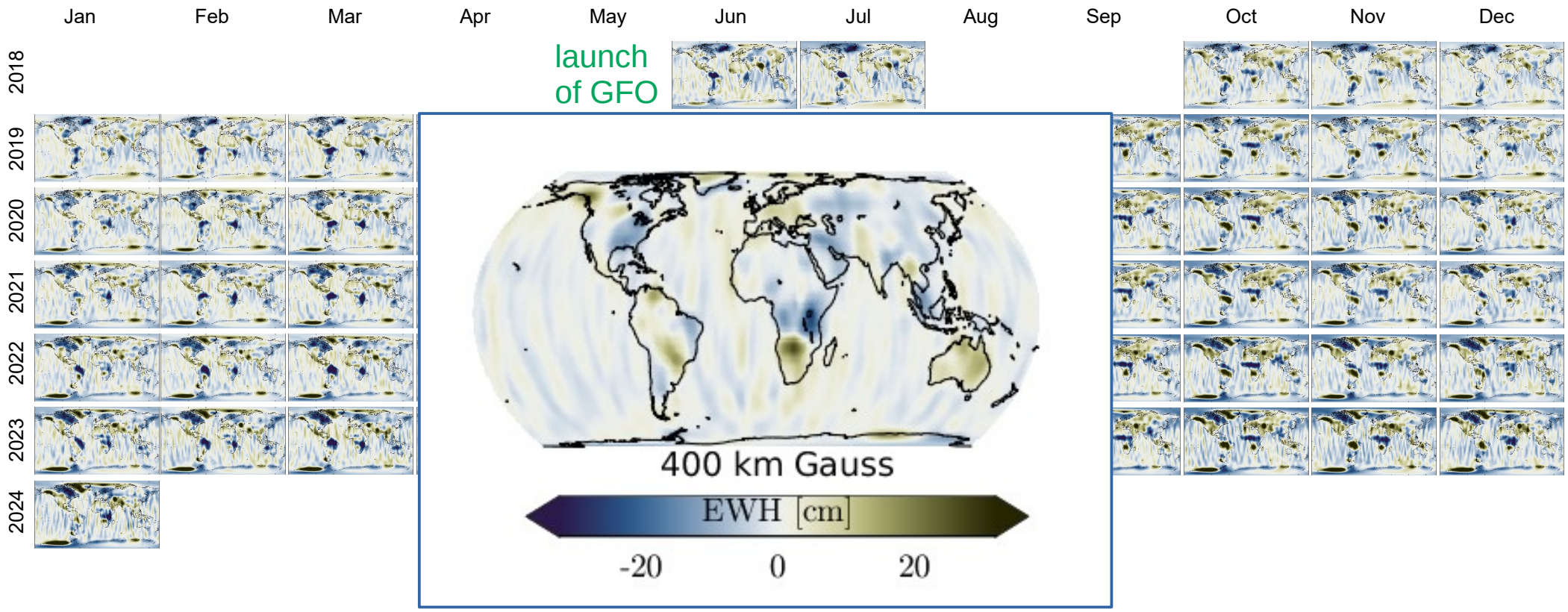


$$r_k = n_{obs} - \frac{\sigma_0^2}{\sigma_k^2}\,\mathrm{tr}\left(\mathbf{N}_k \mathbf{N}^{-1}\right) \qquad \sigma_k^2 = \frac{\boldsymbol{e}_k^T \mathbf{P}_k \boldsymbol{e}_k}{r_k}$$

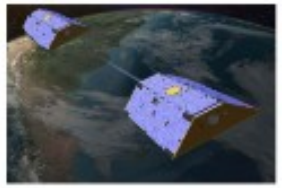
$$\sigma_k^2 \longrightarrow \hat{\boldsymbol{x}} = \left(\sum_{k=1}^{K=3} \frac{\sigma_0^2}{\sigma_k^2}\mathbf{N}_k\right)^{-1} \sum_{k=1}^{K=3} \frac{\sigma_0^2}{\sigma_k^2}\boldsymbol{b}_k$$

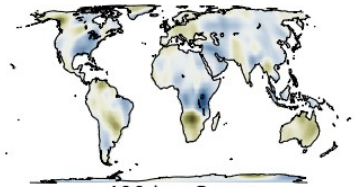
Operational GRACE Follow-On Solution

Mosaic Jun 2018 – Jan 2024



Operational GRACE Follow-On Solution
Monthly gravity fields – parametrisation





Basic parametrisation

- Initial conditions 2x[6]
- Accelerometer bias 2x[3] | [6]
- Accelerometer scaling 2x[3] | [9]

Parameters per arc 24 | 42

since 2023 a full scale matrix estimated

Additional parameters

- 15 min PCA per satellite in
  - radial 2x[96]
  - along-track 2x[96]
  - cross-track 2x[96]

Parameters per arc 576

in daily arcs (30 days):
~ 18000 ‹orbit› parameters
+ 9405 gravity field d/o=2..96

Stochastic Noise Modelling

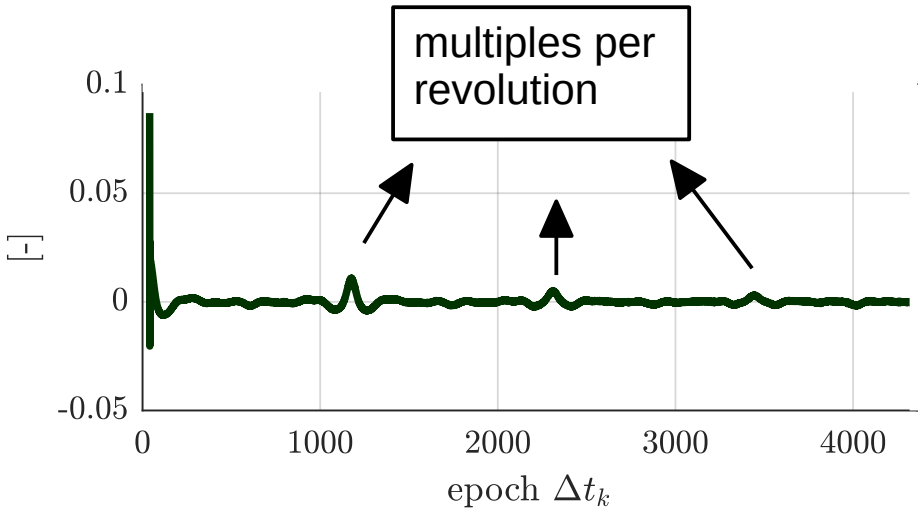
Empirical model from post-fit residuals

Serial correlation of post-fit residuals

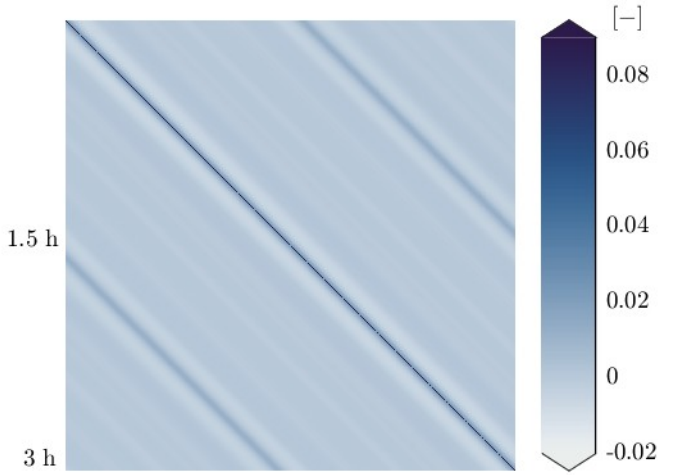
$$\hat{\boldsymbol{e}} = \boldsymbol{l} - \mathbf{A}\,\hat{\boldsymbol{x}}$$ (post-fit residuals)

$$\mathrm{cov}(\Delta t_k) = \frac{1}{N}\sum_{i=0}^{N} \hat{e}(t_i)\,\hat{e}(t_i + \Delta t_k)$$

- stationarity assumed
- biased estimation of auto-covariance
  → covariance matrix nondegenerate



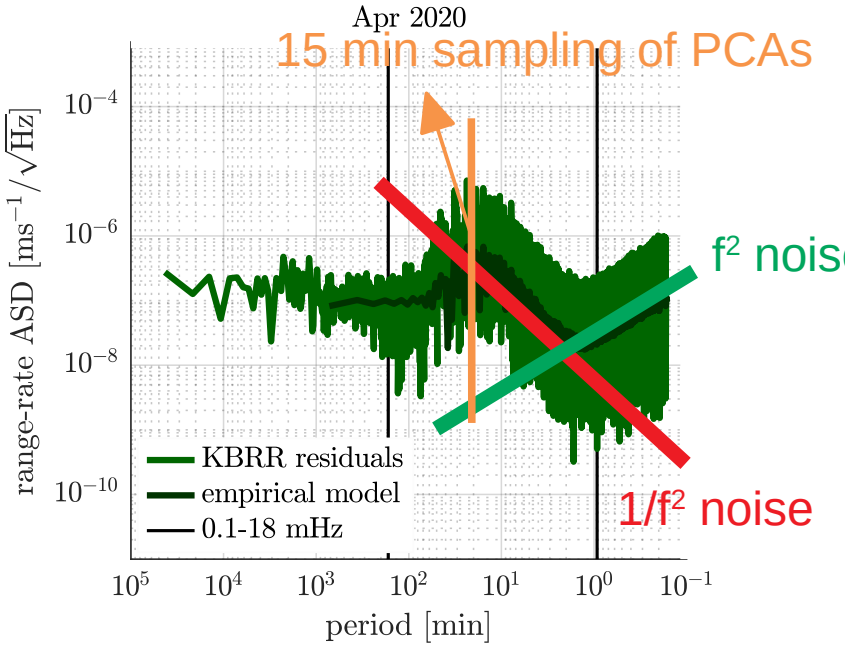
block Toeplitz matrix

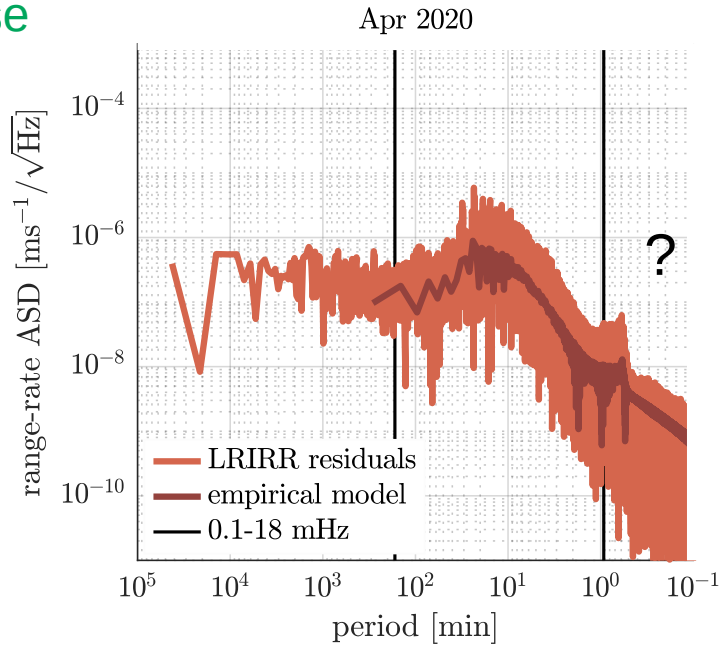


P

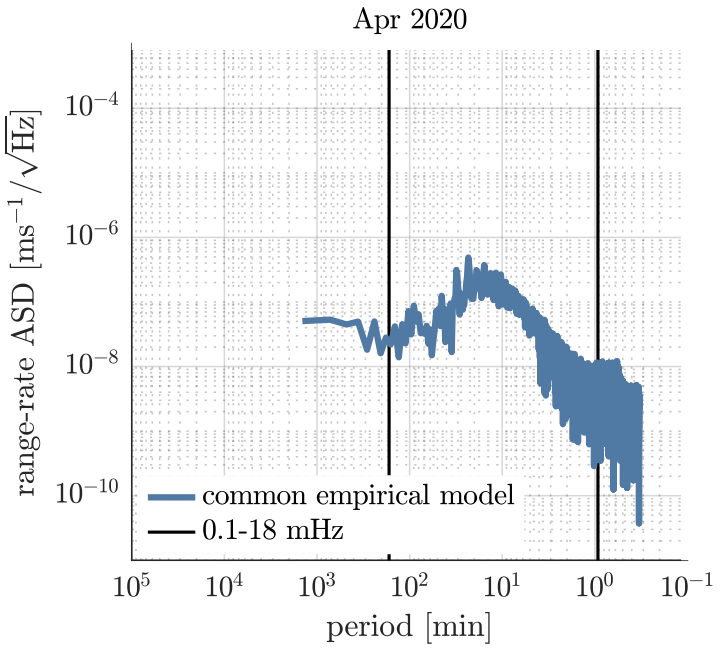
Post-fit Residuals

Spectral domain

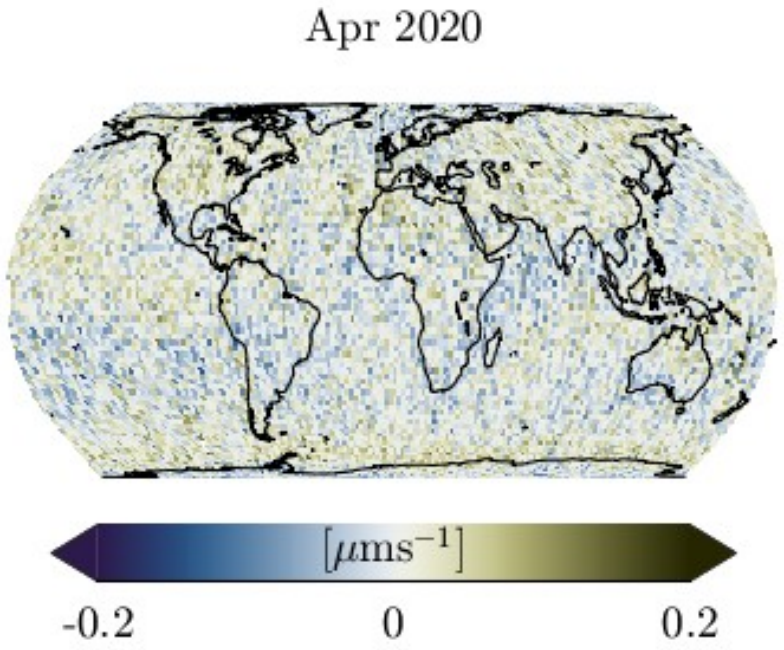


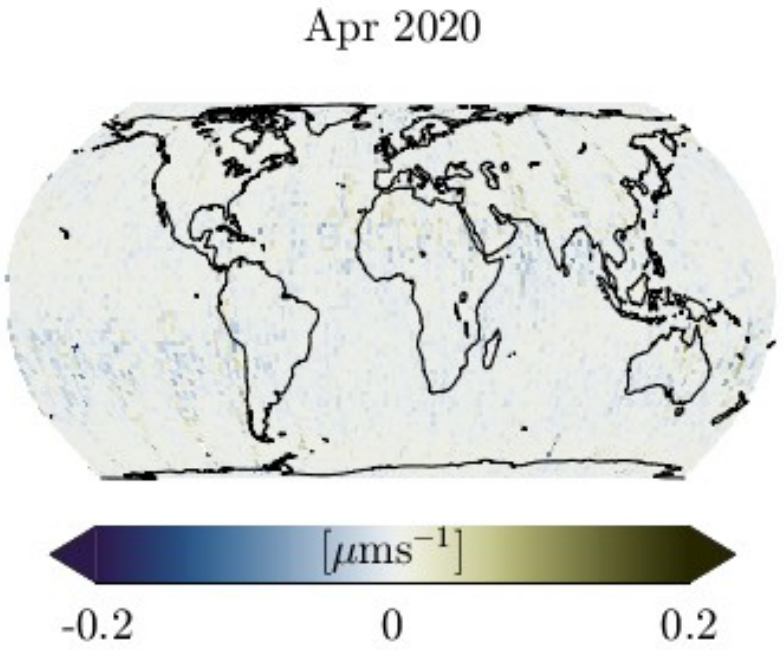


obtained by cross-correlation
not used



Post-fit Residuals
Geographic domain

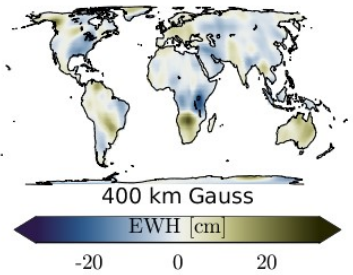


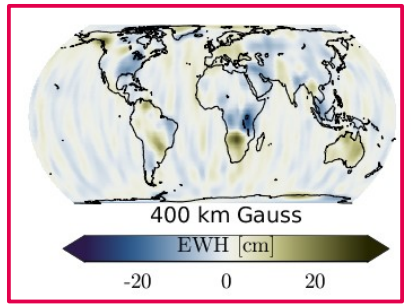


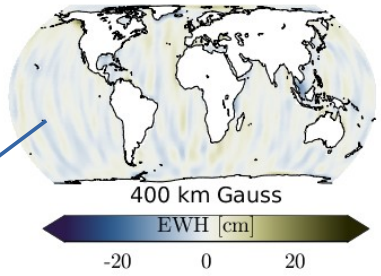
Noise evaluation

RMS over the oceans

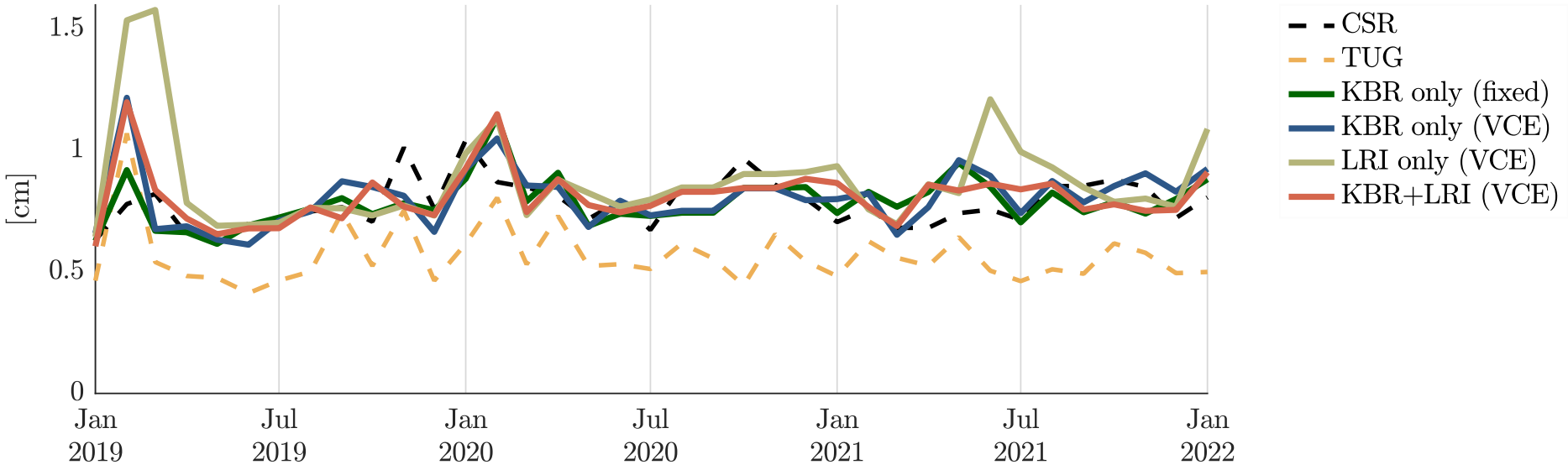
signal





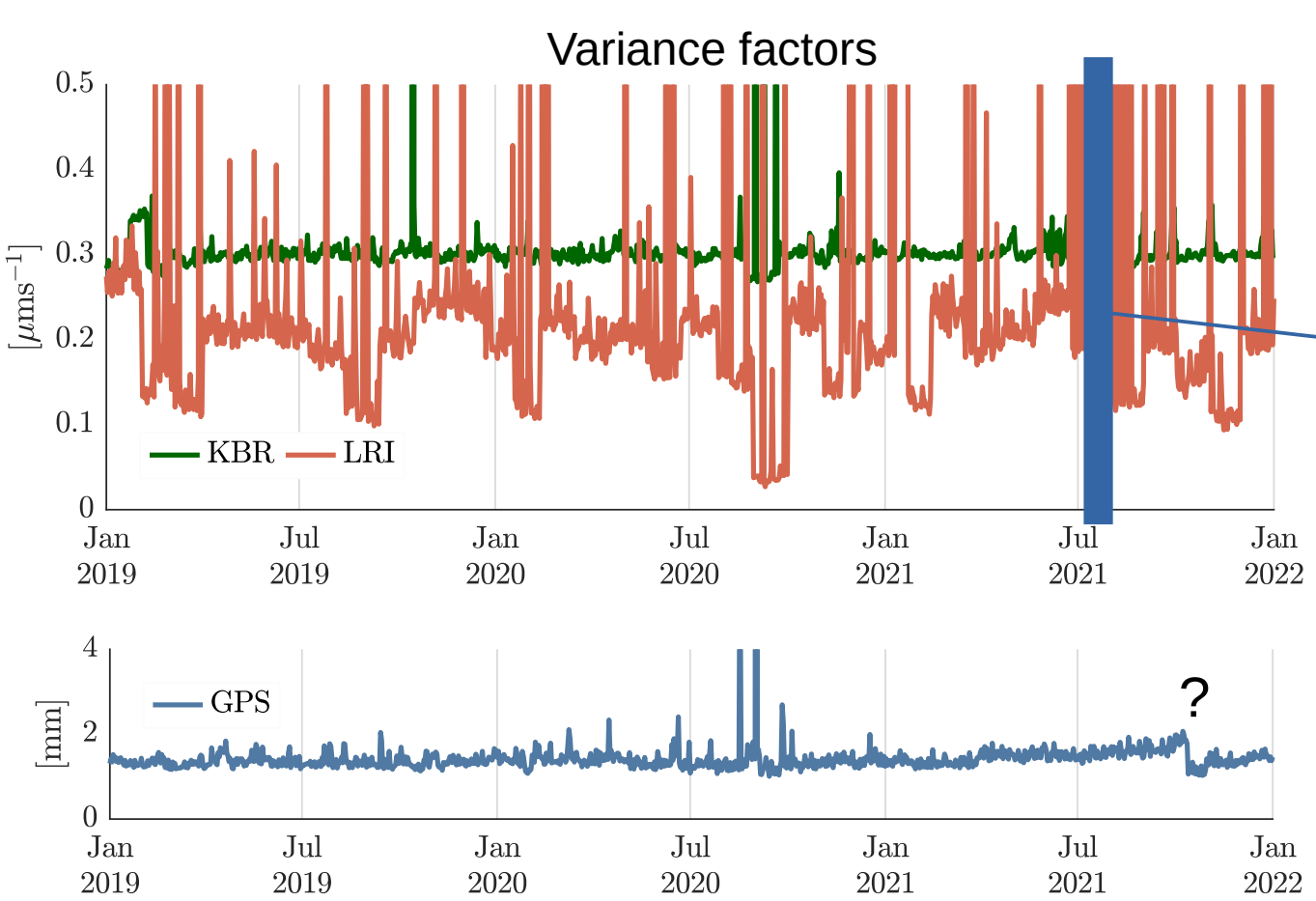


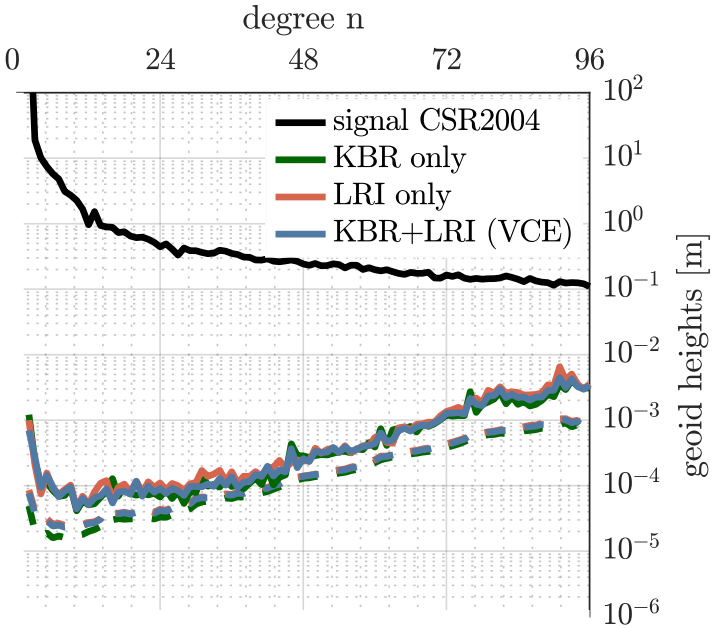
RMS over the oceans



Variance Component Estimation

Arc-wise results

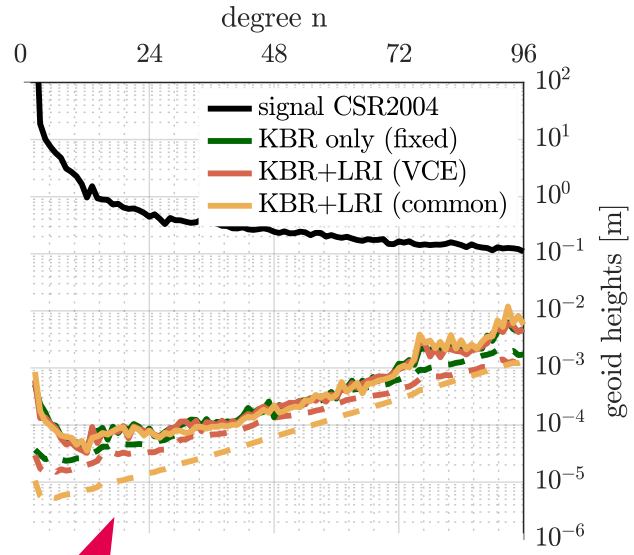




Contribution Analysis
GPS vs. KBR vs. LRI

$$\hat{\boldsymbol{x}} = \left(\sum_{k=1}^{K=3} \mathbf{N}_k \right)^{-1} \sum_{k=1}^{K=3} \boldsymbol{b}_k$$

$$c = \mathrm{diag}\left(\mathbf{N}_k \mathbf{N}^{-1} \right)$$



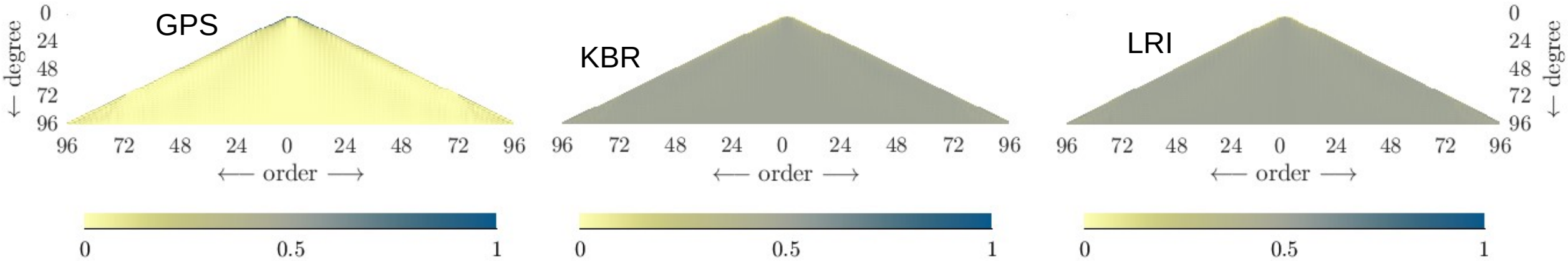
No noise modelling

No VCE (all weights fixed)

Equal weight for KBR and LRI

$\sigma_{KBR} = \sigma_{LRI} = 0.3$ µm/s; $\sigma_{GPS} = 12$ mm

Only common epochs (10 s sampling)



Contribution Analysis
GPS vs. KBR vs. LRI

$$\hat{\boldsymbol{x}} = \left(\sum_{k=1}^{K=3} \mathbf{N}_k \right)^{-1} \sum_{k=1}^{K=3} \boldsymbol{b}_k$$

$$c = \mathrm{diag}\left(\mathbf{N}_k \mathbf{N}^{-1} \right)$$

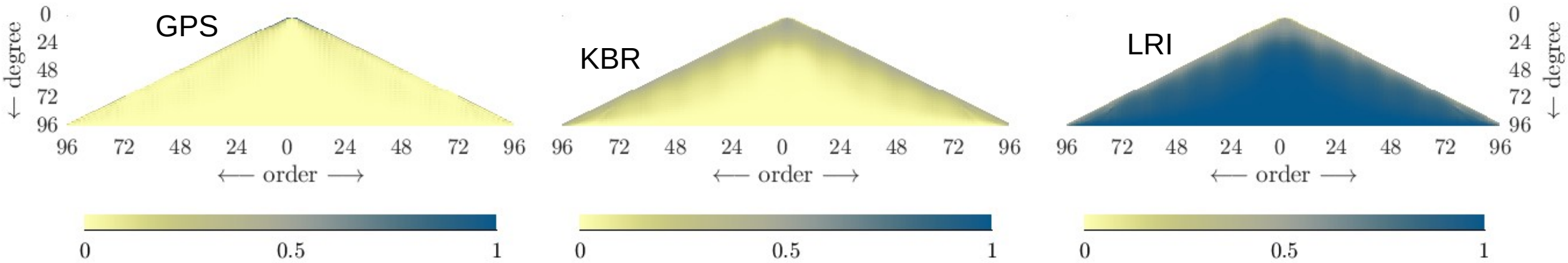
With noise modelling

With VCE

σ_{KBR} ~ 0.3 µm/s; σ_{LRI} ~ 0.2 µm/s

σ_{GPS} ~ 1.6 mm

Only common epochs (10 s sampling)



Contribution Analysis
GPS vs. KBR vs. LRI

$$\hat{\boldsymbol{x}} = \left(\sum_{k=1}^{K=3} \mathbf{N}_k \right)^{-1} \sum_{k=1}^{K=3} \boldsymbol{b}_k$$

$$c = \mathrm{diag}\left(\mathbf{N}_k \mathbf{N}^{-1} \right)$$

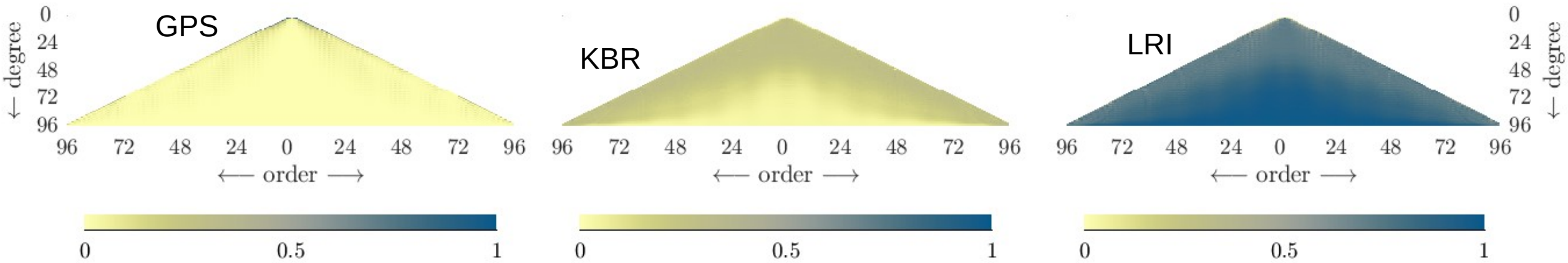
With noise modelling

With VCE

σ_{KBR} ~ 0.3 µm/s; σ_{LRI} ~ 0.2 µm/s

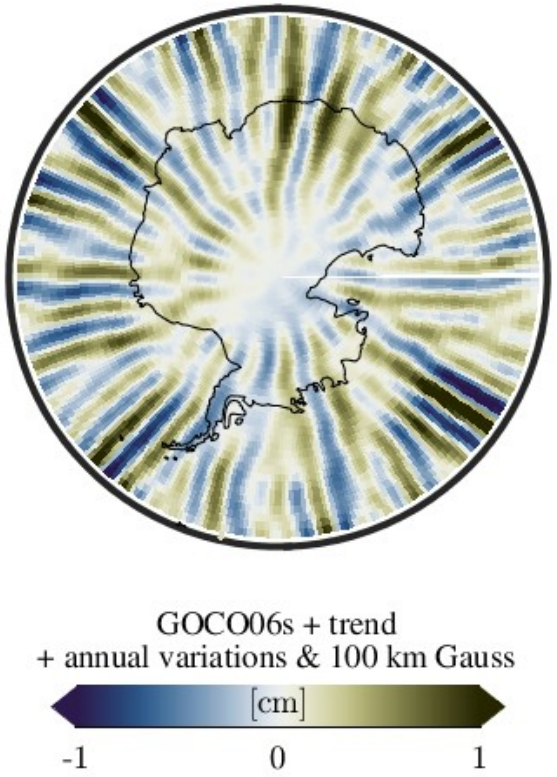
σ_{GPS} ~ 1.6 mm

5 s KBR and 2 s LRI sampling

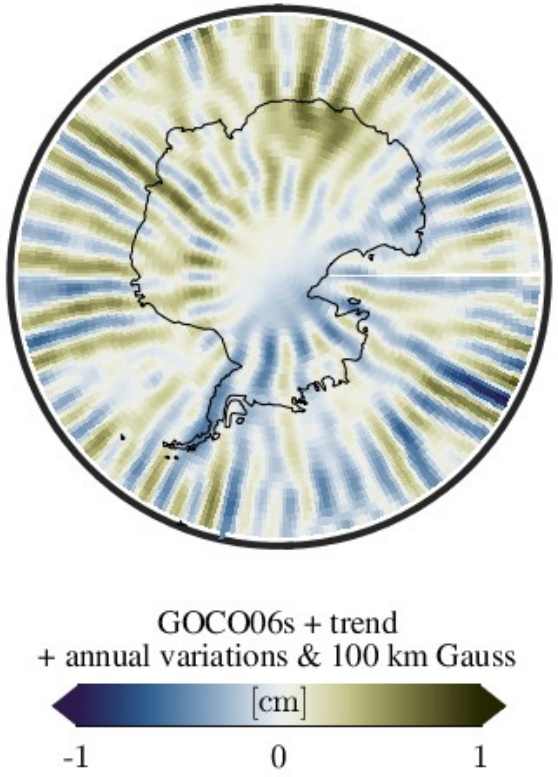


Benefits of adding the LRI
Antarctica

KBR only
Nov 2020



KBR + LRI
Nov 2020



Thank you for your attention

Contact

Martin Lasser

martin.lasser@unibe.ch

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

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

References

B

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