

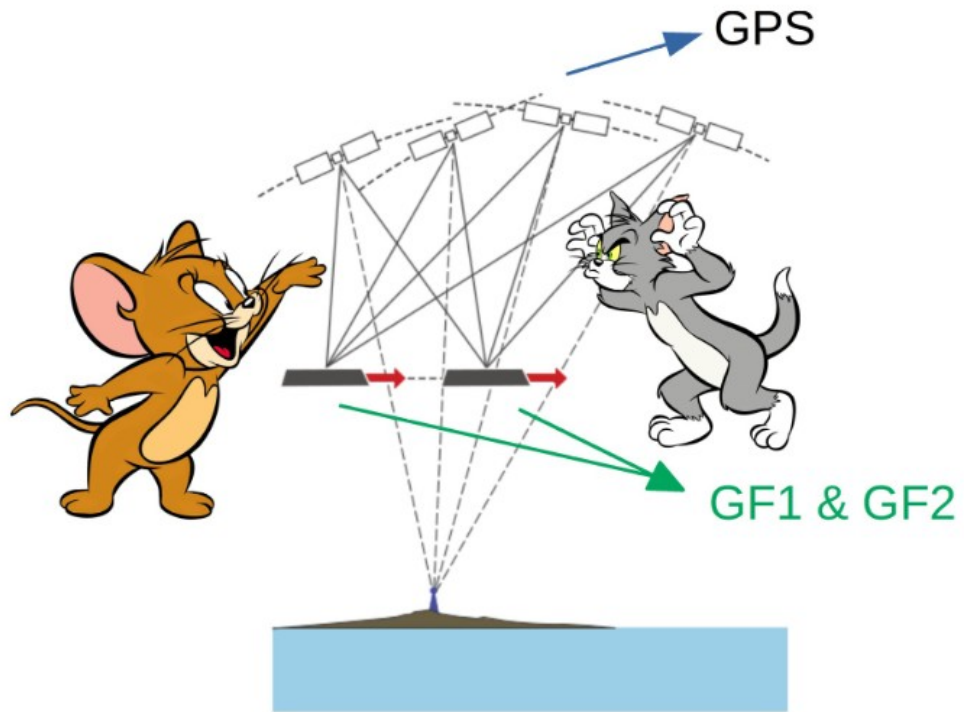
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Integration of Laser Ranging Range-Rate Observations into the GRACE Follow-On Processing at the AIUB

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

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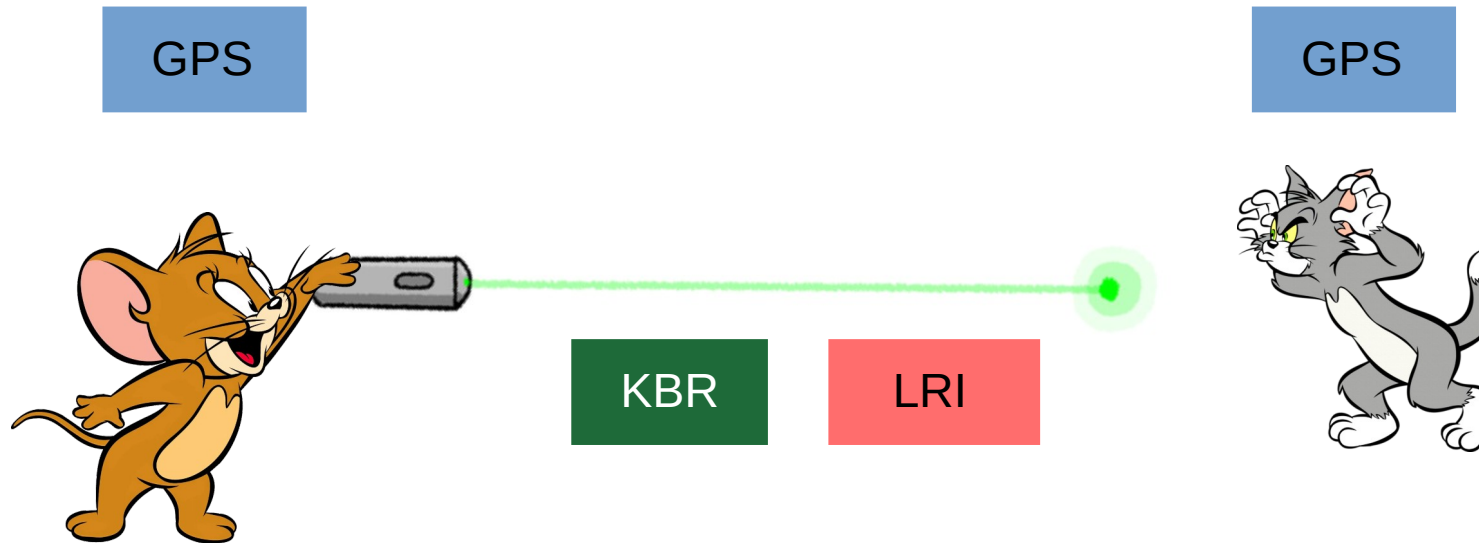
GRACE/GRACE Follow-On Observation concept



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GRACE Follow-On

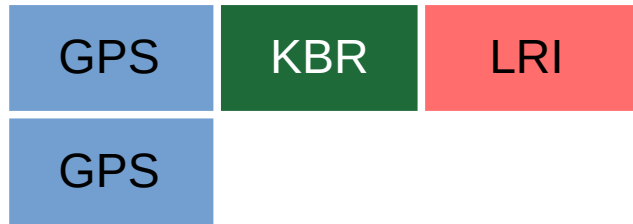
Observables in L2 processing



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GRACE Follow-On

Observables in L2 processing



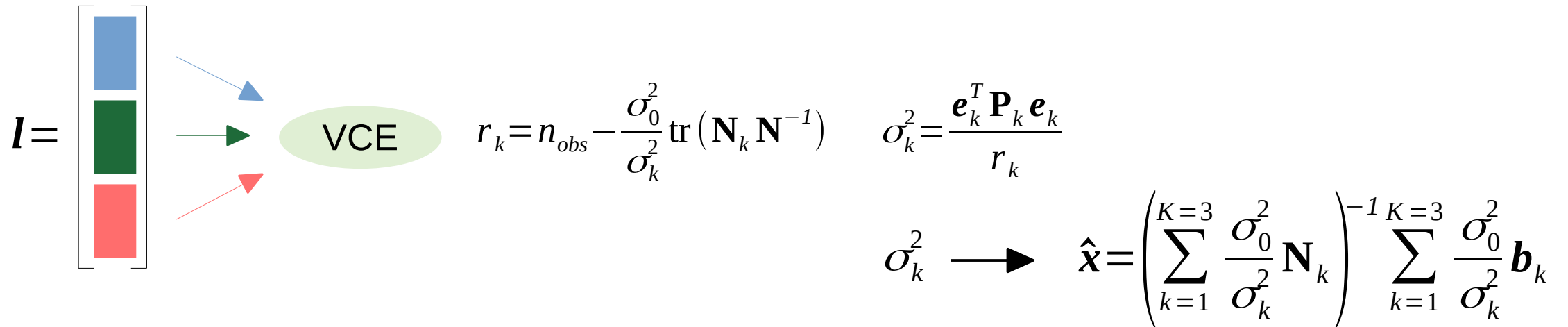
$$l = \begin{bmatrix} \text{GPS} \\ \text{KBR} \\ \text{LRI} \end{bmatrix} \begin{matrix} \rightarrow \mathbf{A}_1 \mathbf{P}_1 \\ \rightarrow \mathbf{A}_2 \mathbf{P}_2 \\ \rightarrow \mathbf{A}_3 \mathbf{P}_3 \end{matrix} \left. \vphantom{\begin{matrix} \rightarrow \mathbf{A}_1 \mathbf{P}_1 \\ \rightarrow \mathbf{A}_2 \mathbf{P}_2 \\ \rightarrow \mathbf{A}_3 \mathbf{P}_3 \end{matrix}} \right\} \begin{matrix} \mathbf{N} = (\mathbf{A}^T \mathbf{P} \mathbf{A}) \\ \mathbf{b} = \mathbf{A}^T \mathbf{P} l \end{matrix} \rightarrow \hat{\mathbf{x}} = \left(\sum_{k=1}^{K=3} \mathbf{N}_k \right)^{-1} \sum_{k=1}^{K=3} \mathbf{b}_k$$

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GRACE Follow-On Observables



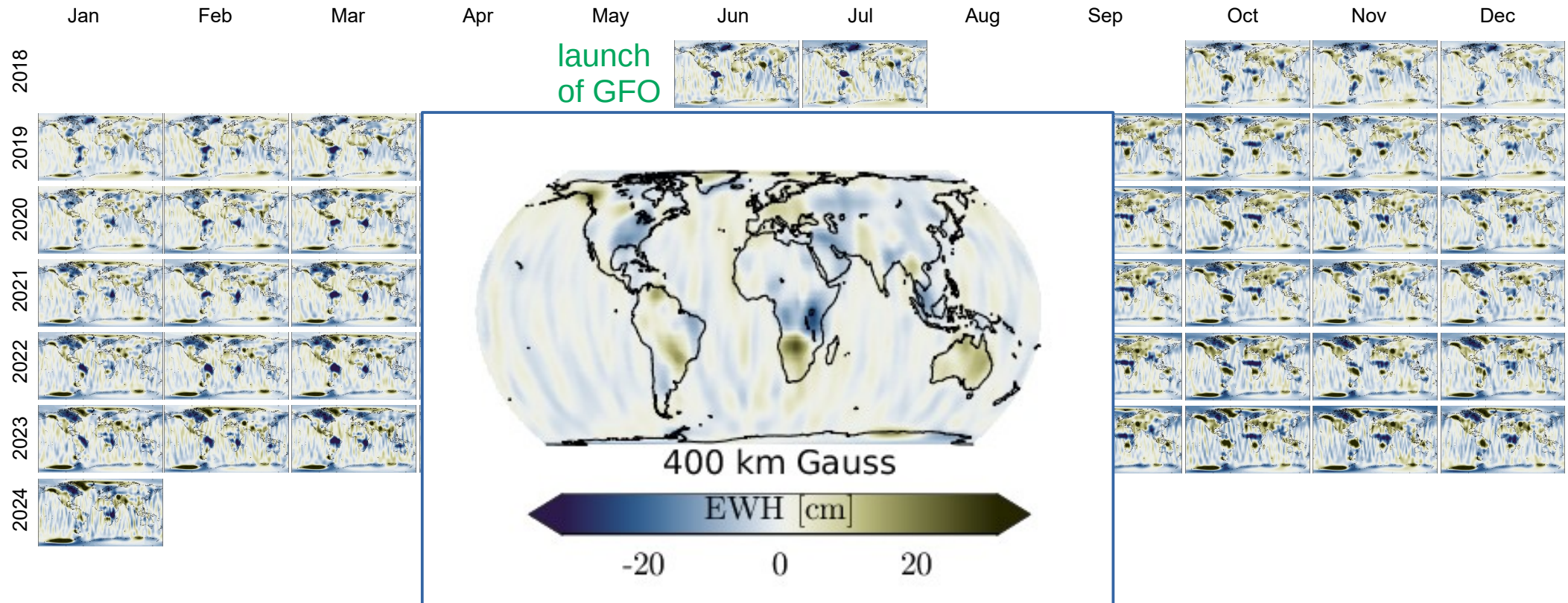
VCE: Each group of observations gets a weight based on its contribution to the final solution



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Operational GRACE Follow-On Solution

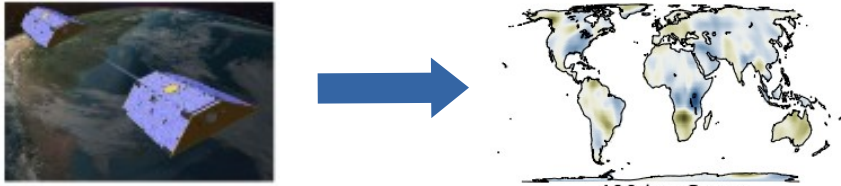
Mosaic Jun 2018 – Jan 2024



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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

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Stochastic Noise Modelling

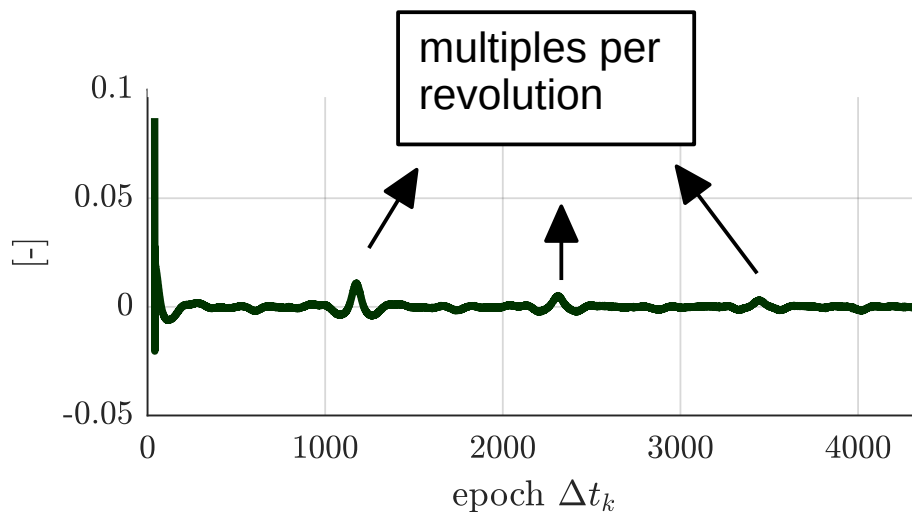
Empirical model from post-fit residuals

Serial correlation of post-fit residuals

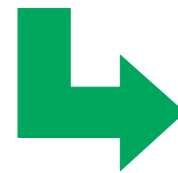
$$\hat{e} = l - A \hat{x} \quad (\text{post-fit residuals})$$

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

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



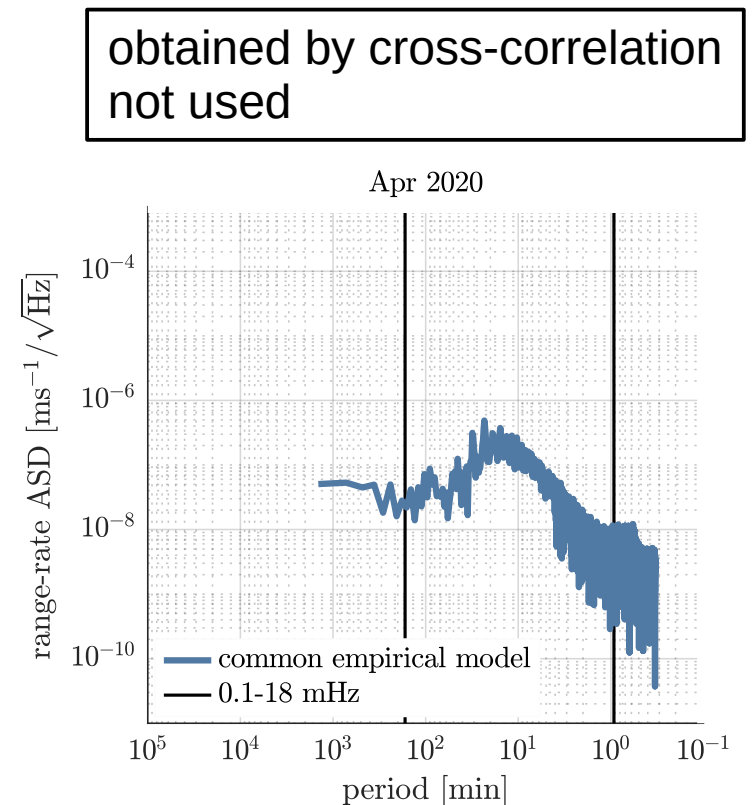
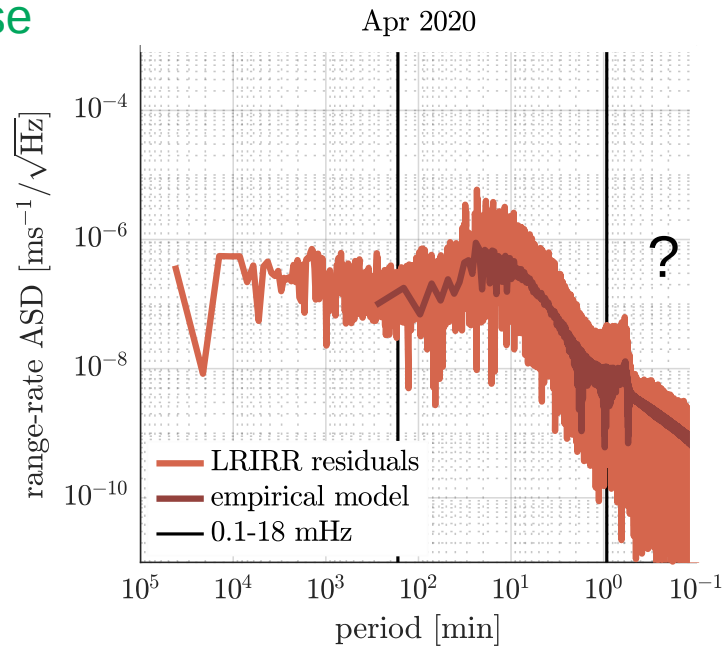
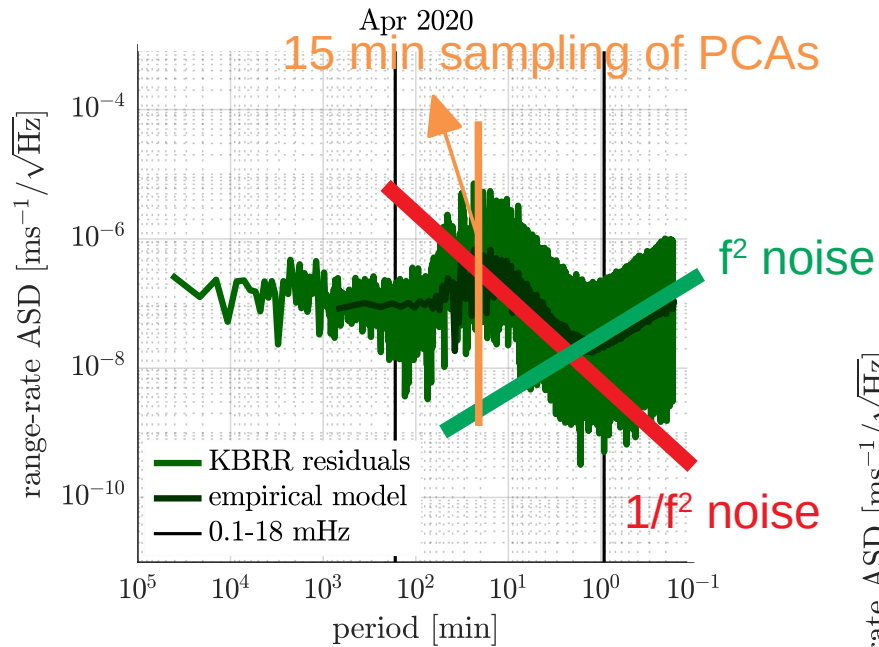
block
Toeplitz
matrix

**P**

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Post-fit Residuals

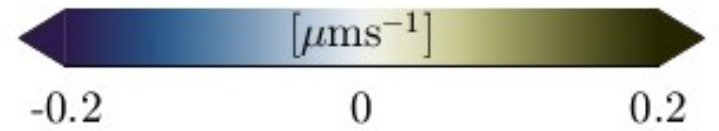
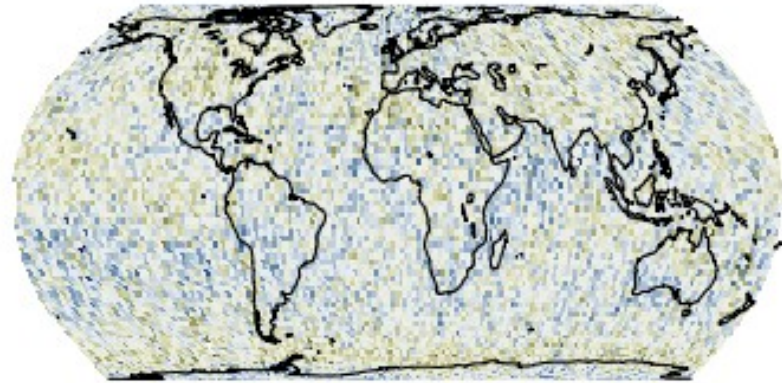
Spectral domain



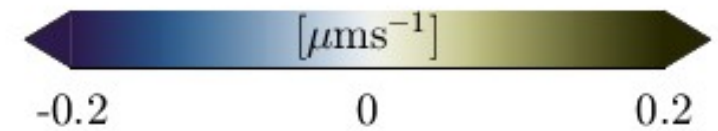
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Post-fit Residuals Geographic domain

Apr 2020

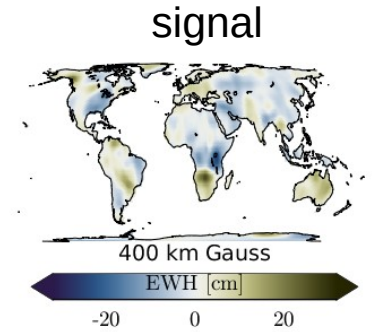
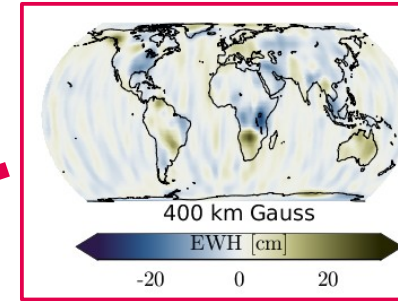
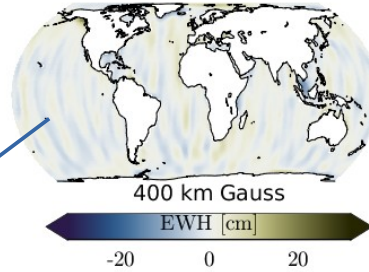


Apr 2020

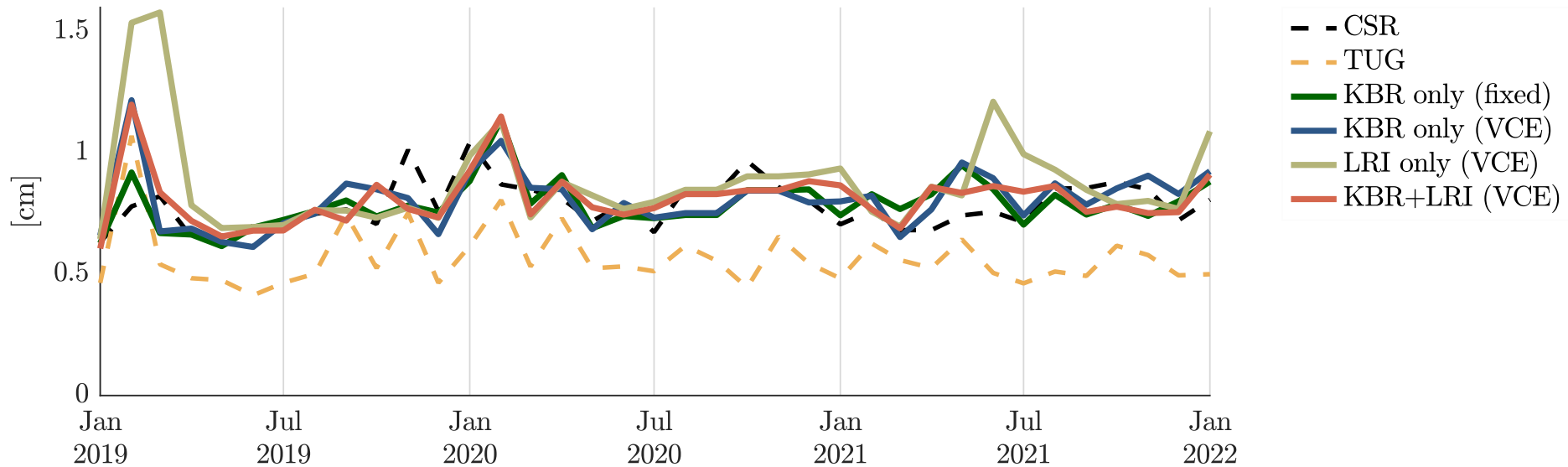


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Noise evaluation RMS over the oceans



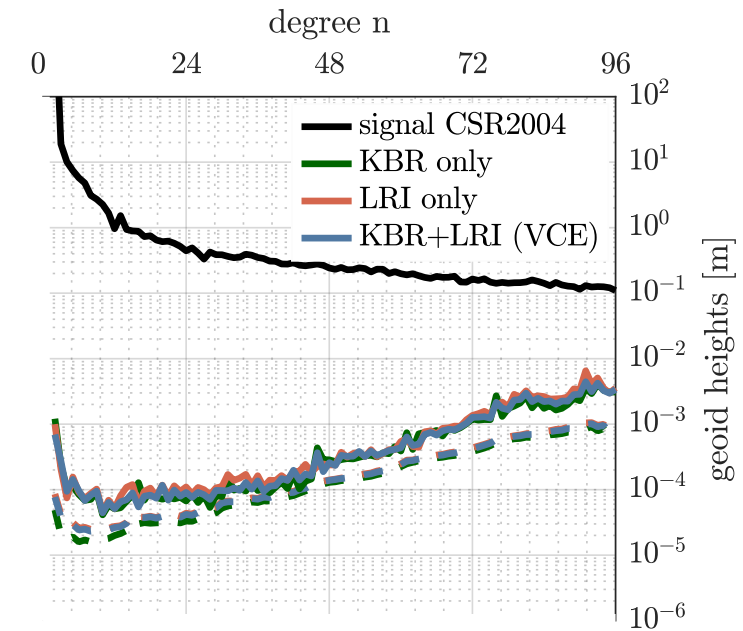
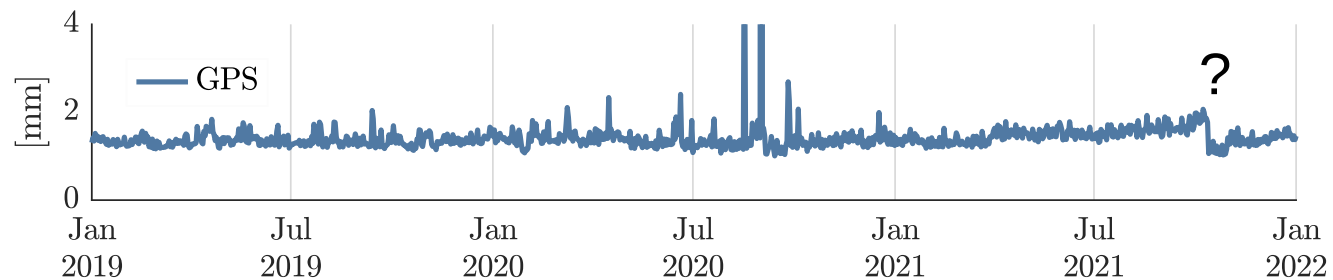
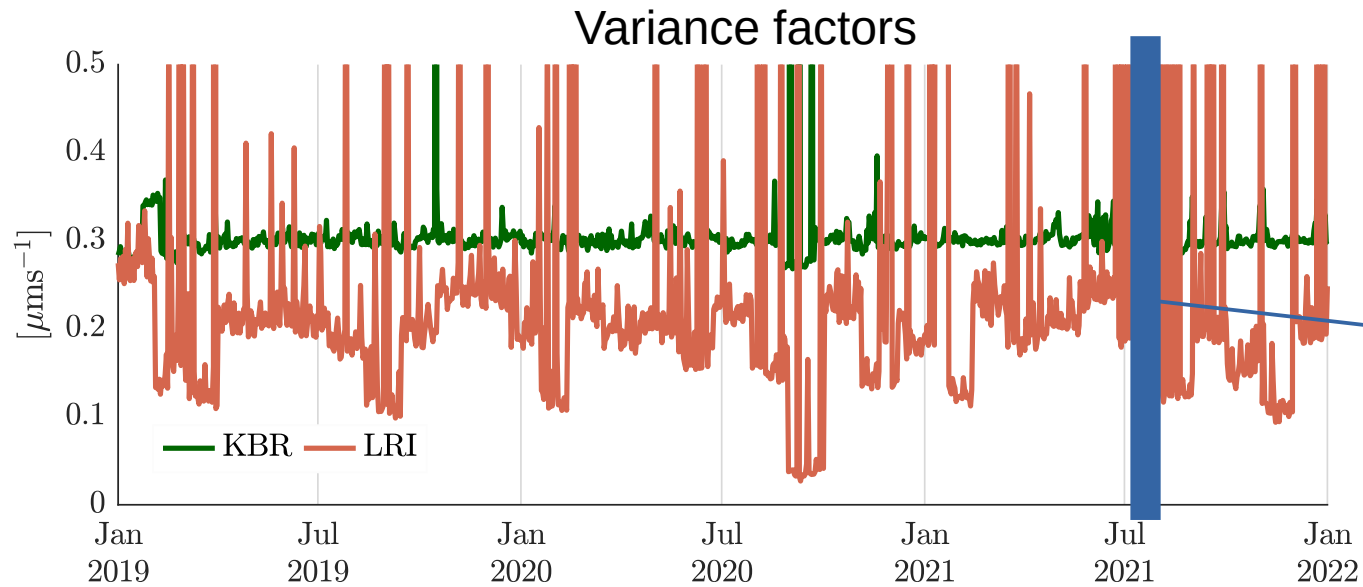
RMS over the oceans



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Variance Component Estimation

Arc-wise results



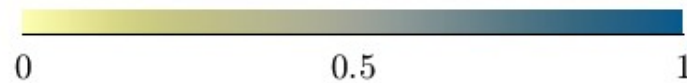
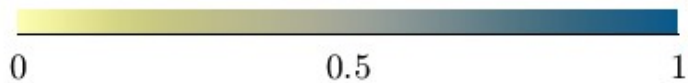
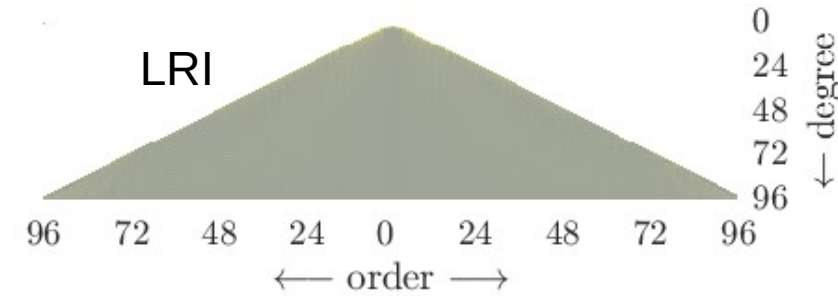
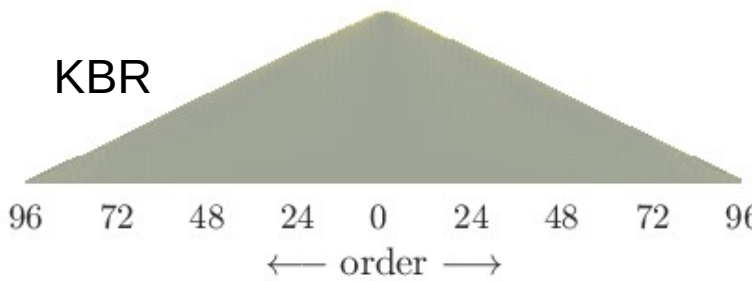
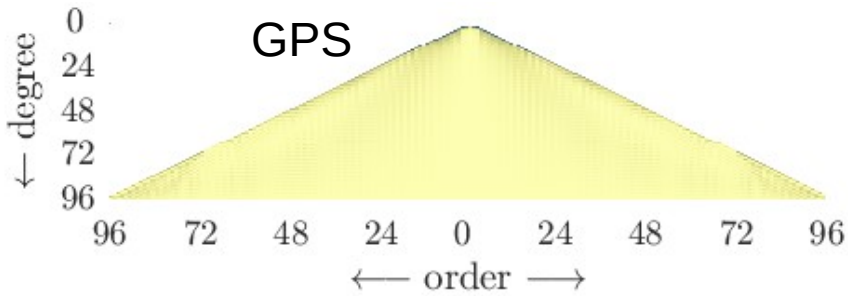
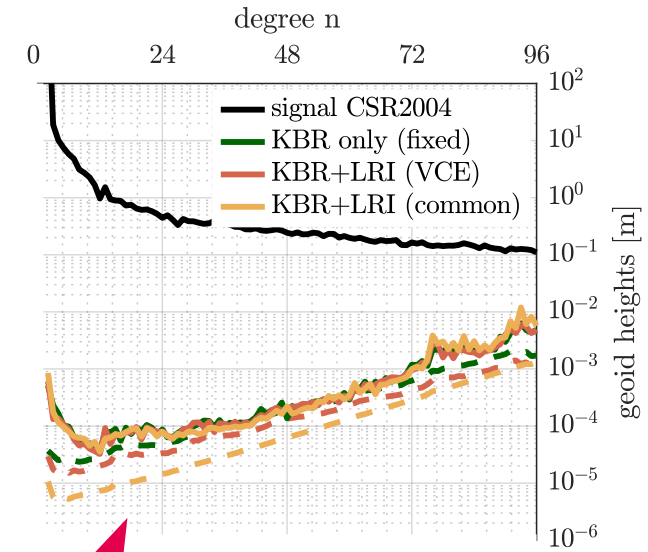
u^b Contribution Analysis

GPS vs. KBR vs. LRI

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

■ \mathbf{N}_k
■ \mathbf{b}_k
■ $c = \text{diag}(\mathbf{N}_k \mathbf{N}_k^{-1})$

- No noise modelling
- No VCE (all weights fixed)
- Equal weight for KBR and LRI
- $\sigma_{\text{KBR}} = \sigma_{\text{LRI}} = 0.3 \mu\text{m/s}$; $\sigma_{\text{GPS}} = 12 \text{ mm}$
- Only common epochs (10 s sampling)



u^b Contribution Analysis

GPS vs. KBR vs. LRI

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

■ \mathbf{b}_k
■ \mathbf{N}_k
■ $\mathbf{c} = \text{diag}(\mathbf{N}_k \mathbf{N}_k^{-1})$

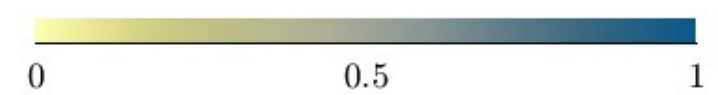
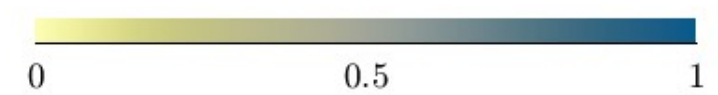
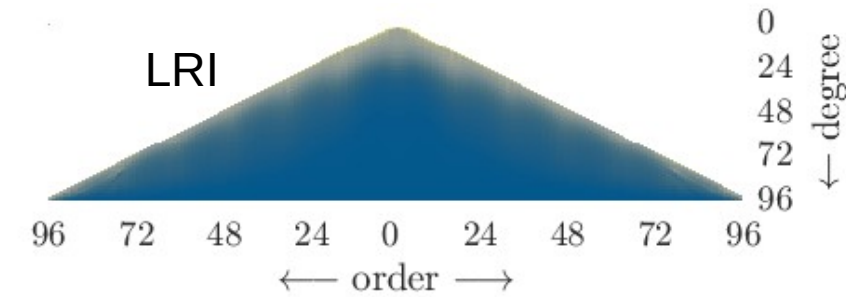
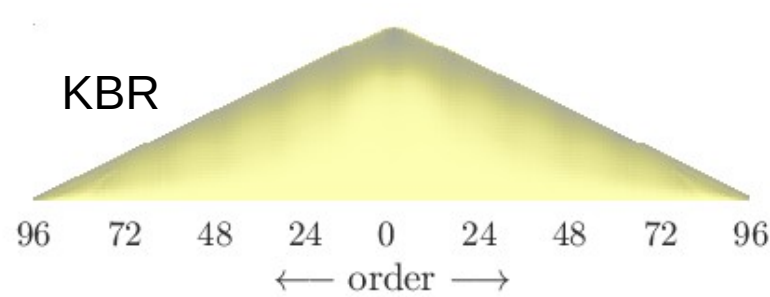
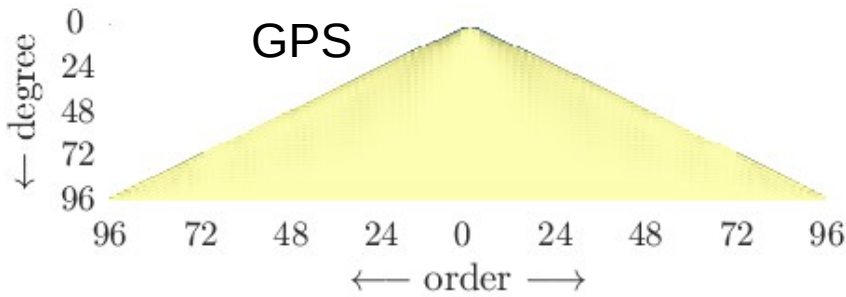
With noise modelling

With VCE

$\sigma_{\text{KBR}} \sim 0.3 \mu\text{m/s}$; $\sigma_{\text{LRI}} \sim 0.2 \mu\text{m/s}$

$\sigma_{\text{GPS}} \sim 1.6 \text{ mm}$

Only common epochs (10 s sampling)



u^b Contribution Analysis

GPS vs. KBR vs. LRI

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

■ \mathbf{b}_k
■ \mathbf{N}_k
■ $\mathbf{c} = \text{diag}(\mathbf{N}_k \mathbf{N}_k^{-1})$

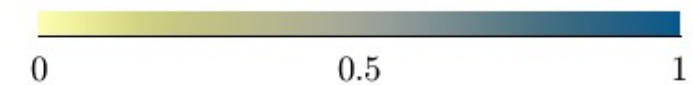
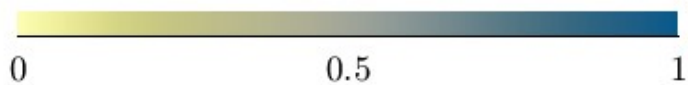
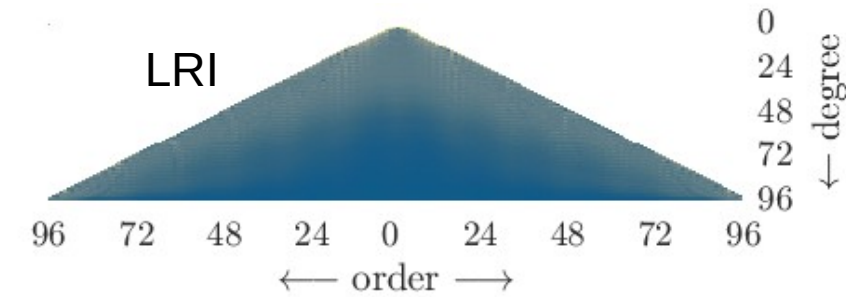
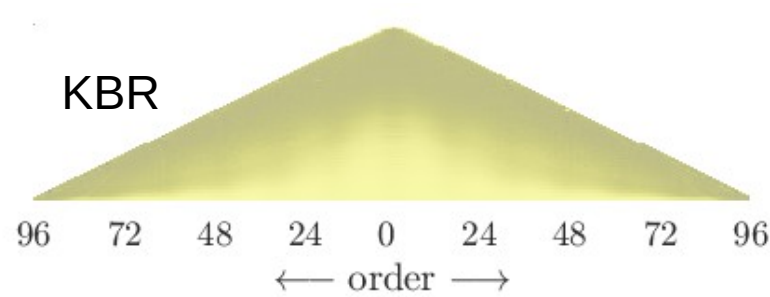
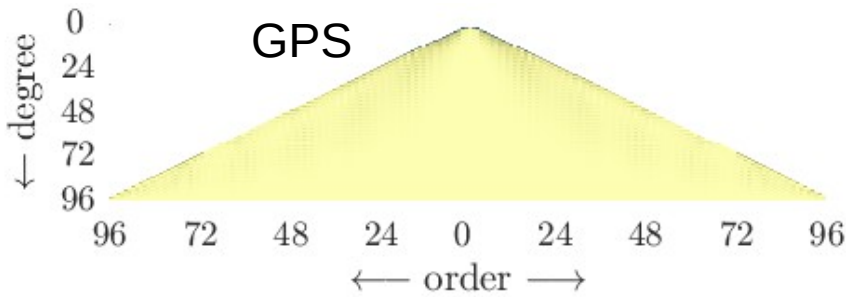
With noise modelling

With VCE

$\sigma_{\text{KBR}} \sim 0.3 \mu\text{m/s}$; $\sigma_{\text{LRI}} \sim 0.2 \mu\text{m/s}$

$\sigma_{\text{GPS}} \sim 1.6 \text{ mm}$

5 s KBR and 2 s LRI sampling

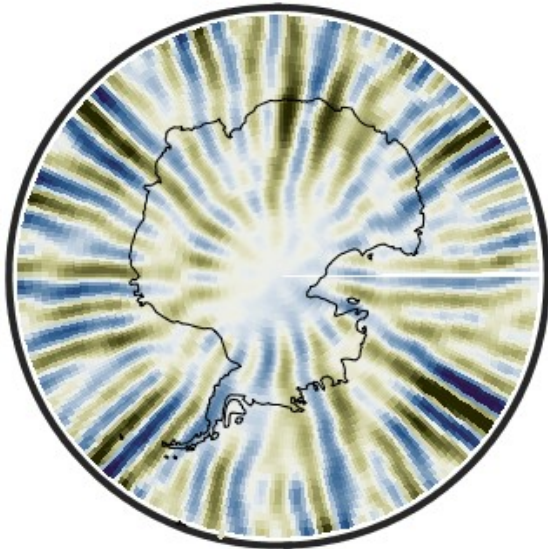


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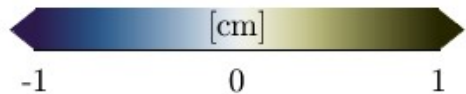
Benefits of adding the LRI

Antarctica

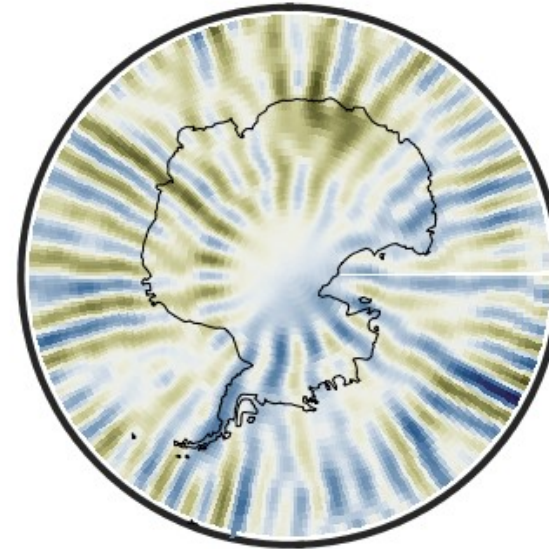
KBR only
Nov 2020



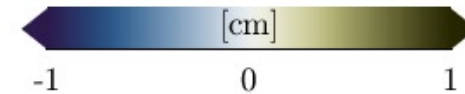
GOCO06s + trend
+ annual variations & 100 km Gauss



KBR + LRI
Nov 2020



GOCO06s + trend
+ annual variations & 100 km Gauss



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Thank you for your attention

Contact

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martin.lasser@unibe.ch

References

A

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B

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