Time-variable gravity field determination from GRACE-FO data at AIUB

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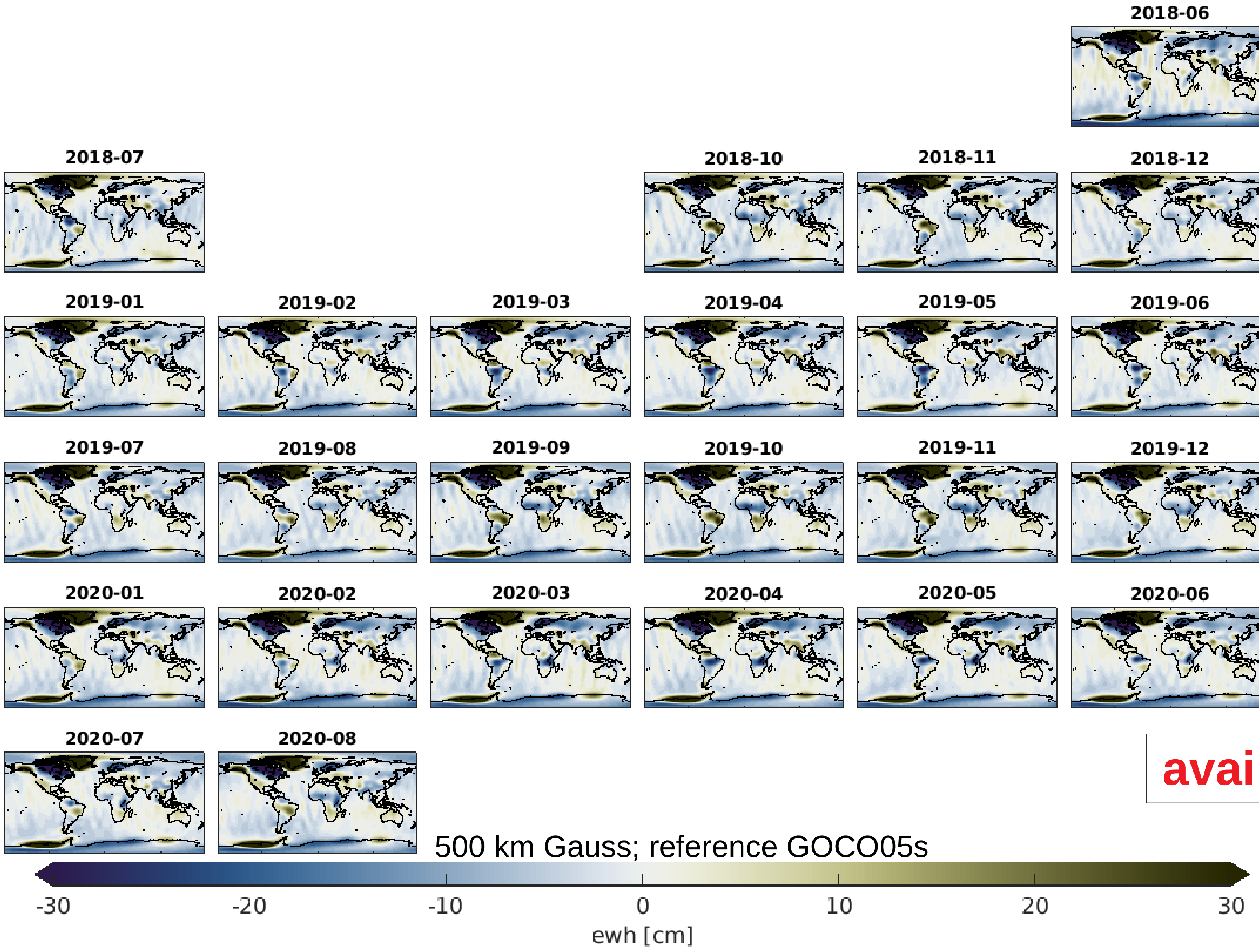
GRACE & GRACE-FO Science Team Meeting
Oct. 26-29, 2020
Online

Time series AIUB-GRACE-FO-operational



available on ICGEM

Modelling

Parametrisation
6 initial conditions (daily)
accelerometer bias and scaling (daily)
15 min piecewise constant accelerations (PCA) (daily)
gravity field coefficients (monthly)

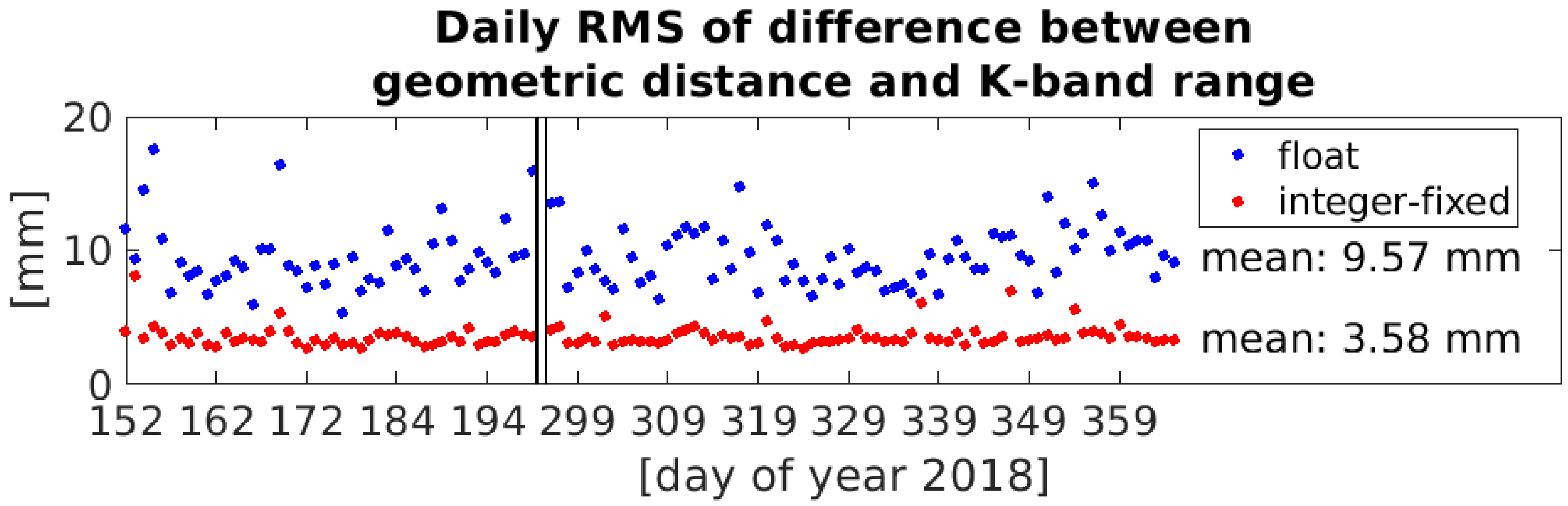
$$\sum_{d=1}^{31} \text{accumulate normal equations to a monthly solution}$$

Modelling cont'd

Force models	
Gravity field	Internal AIUB static GRACE field (d/o=160)
Celestial bodies	JPL DE421 (all planets + Pluto)
Mean pole	Linear
Solid Earth tides	IERS2010
Solid Earth pole tides	IERS2010
Ocean tides	FES2014b (+ admittances from IfG) (d/o=100)
Ocean pole tides	Desai
Atmospheric tides	AOD RL06 (d/o=100)
Atmospheric & oeanic dealiasing	AOD RL06 (d/o=100)
Relativistic effects	IERS2010
Non-conservative forces	Accelerometer L1b (IfG)

Kinematic positions

- Integer-fixed kinematic positions
  → CODE clocks and phase biases (Schaer et al., 2020, J. Geod. [in review])



Individual arcs feature reduced position noise

Influence of integer-fixed positions

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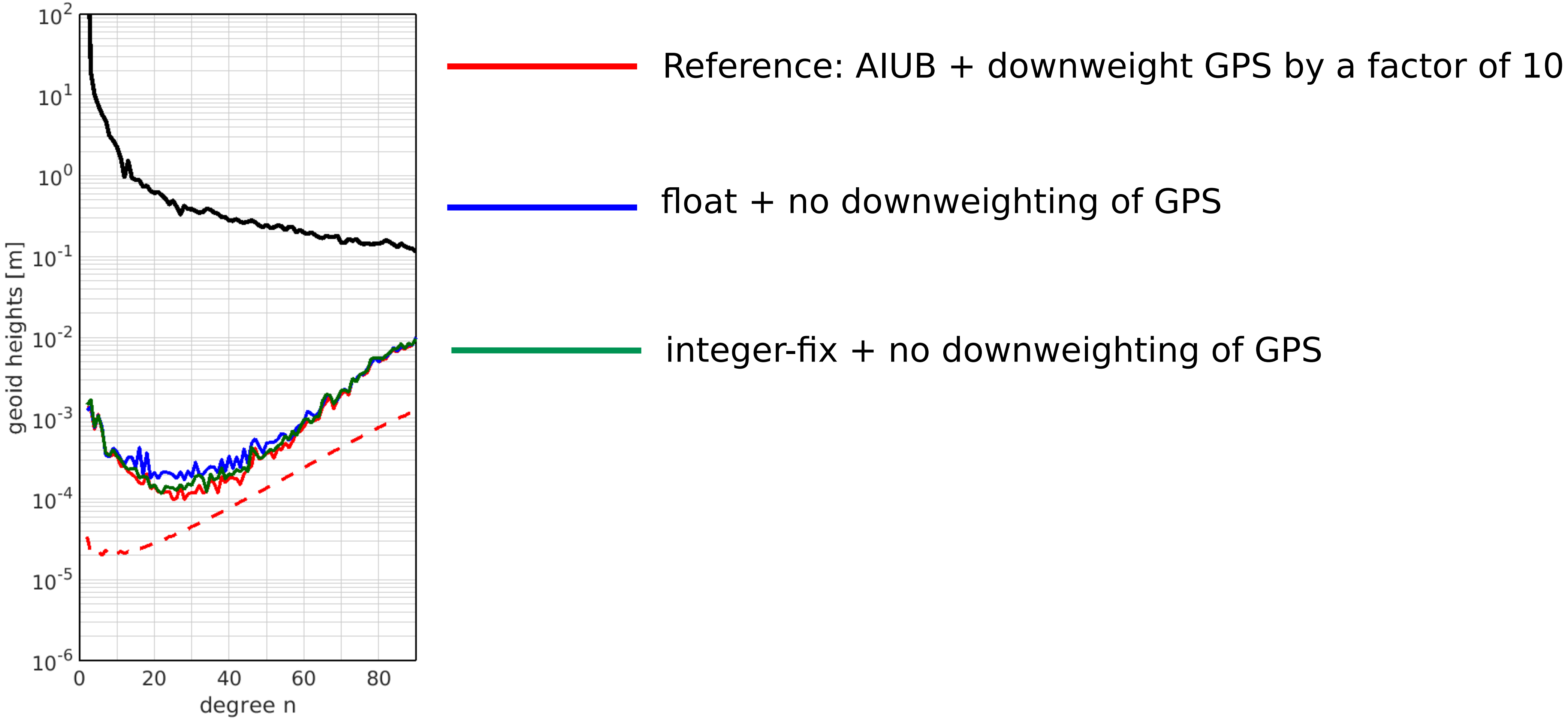
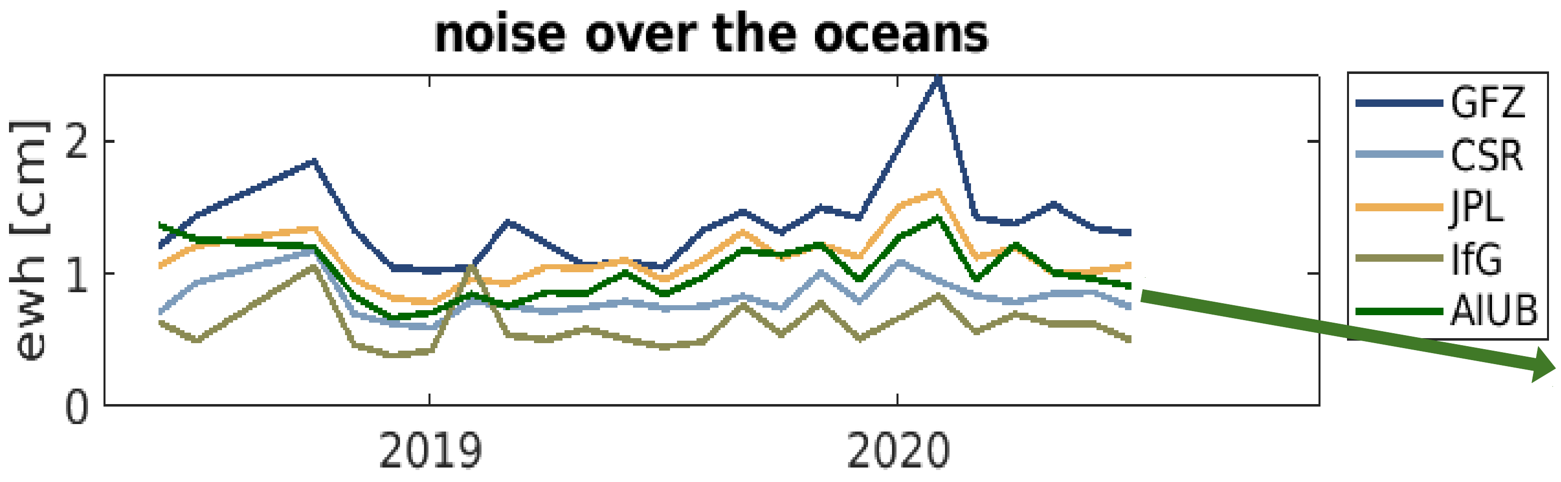
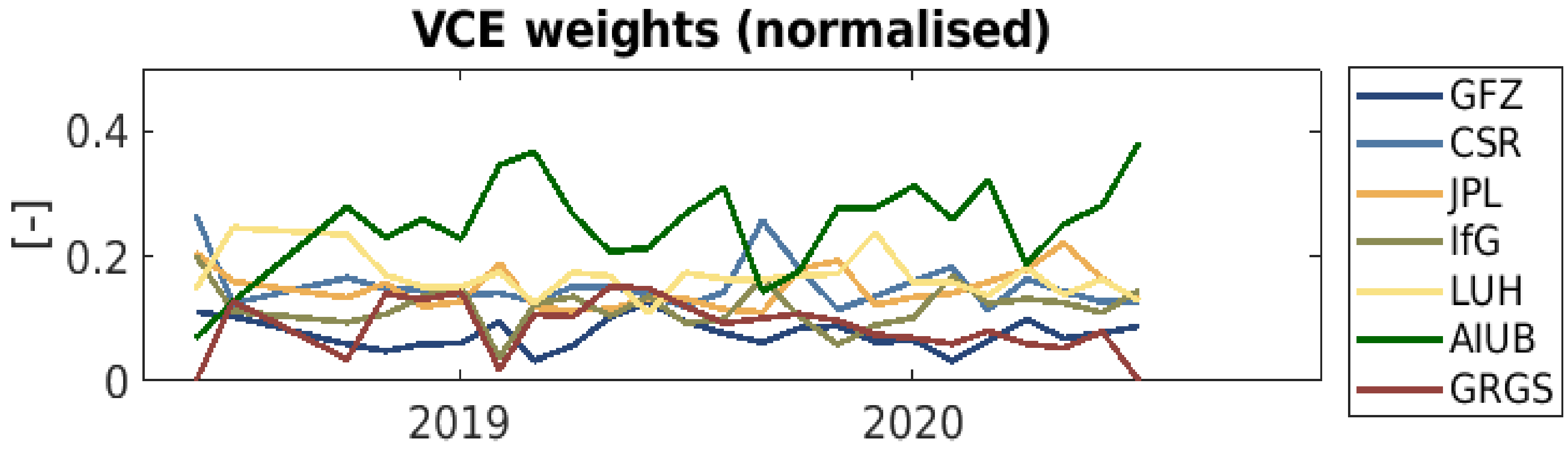


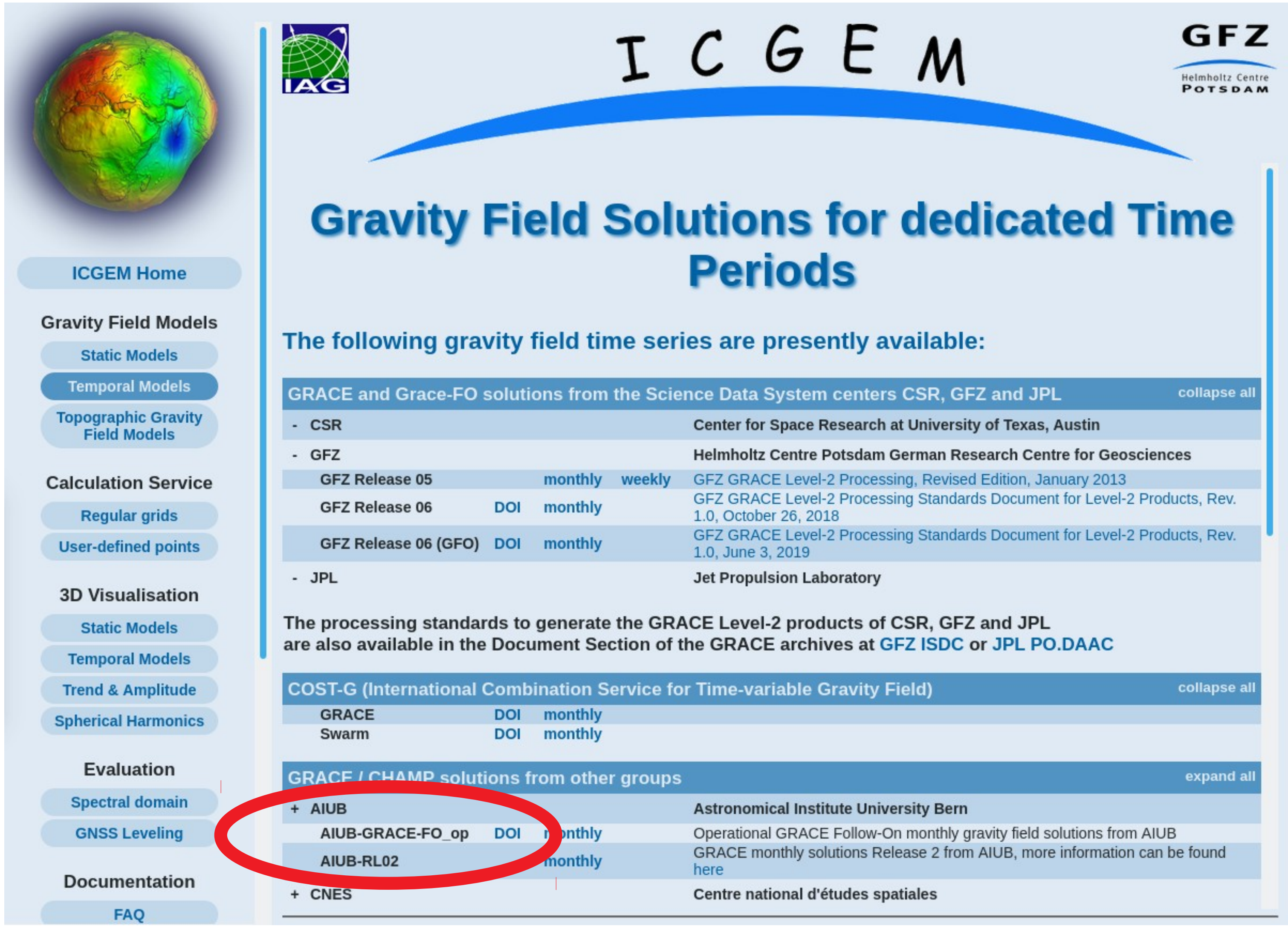
Performance



Large contribution from IfG-ACT!



Level-2 product availability



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Observation data processing

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

Each a block of observations
(only observations within one block might be correlated)

$$\begin{bmatrix} \boldsymbol{l}_1 \\ \boldsymbol{l}_2 \\ \vdots \\ \boldsymbol{l}_n \end{bmatrix} \;\rightarrow\; \mathbf{N}_k = \left(\mathbf{A}_k^T \mathbf{P}_k \mathbf{A}_k\right)^{-1} \quad \text{and} \quad \boldsymbol{n}_k = \mathbf{A}_k^T \mathbf{P}_k \boldsymbol{l}_k \;\rightarrow\; \hat{\boldsymbol{x}} = \left(\sum_{k=1}^{n} \mathbf{N}_k\right)^{-1} \sum_{k=1}^{n} \boldsymbol{n}_k$$

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Observation data weighting: VCE

$$\begin{bmatrix} \boldsymbol{l}_1 \\ \boldsymbol{l}_2 \\ \vdots \\ \boldsymbol{l}_n \end{bmatrix}$$

VCE:

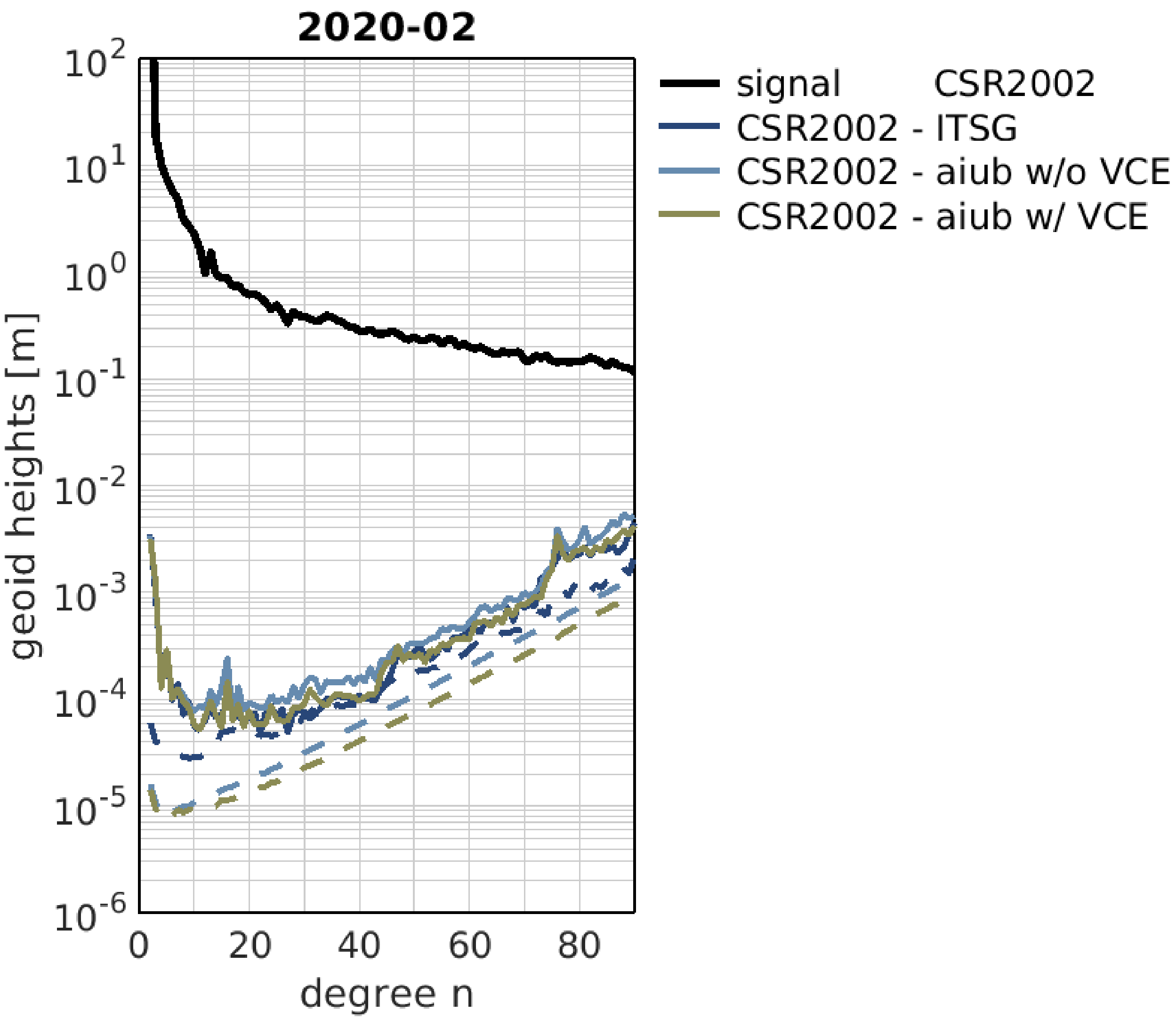
$$r_k = n_{obs} - \frac{\sigma_0^2}{\sigma_k^2} \operatorname{tr}\left(\mathbf{N}_k \mathbf{N}^{-1}\right)$$

$$\sigma_k^2 = \frac{\boldsymbol{e}_k^T \mathbf{P}_k \boldsymbol{e}_k}{r_k}$$

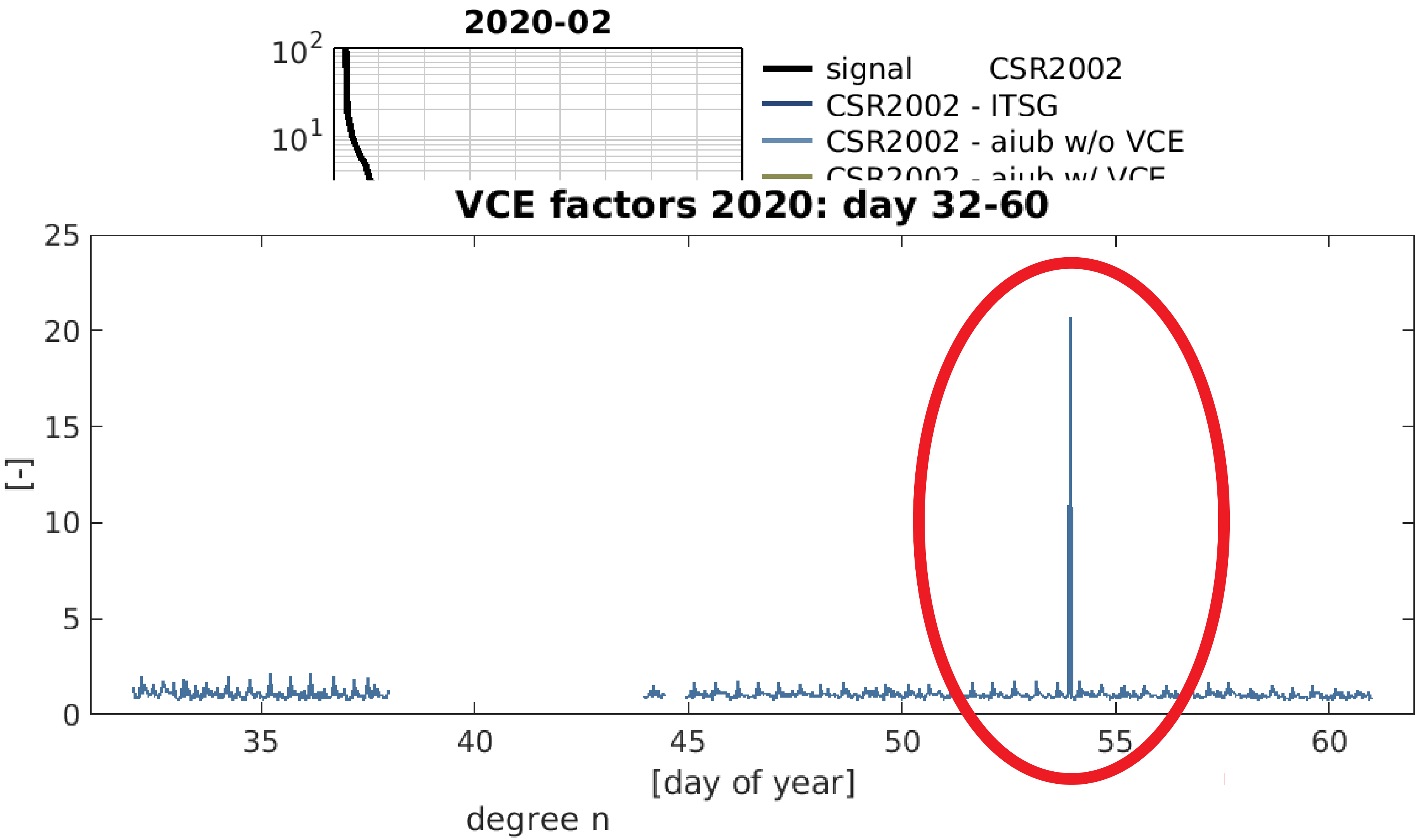
$$\hat{\boldsymbol{x}} = \left(\sum_{k=1}^{n} \frac{\sigma_0^2}{\sigma_k^2} \mathbf{N}_k \right)^{-1} \sum_{k=1}^{n} \frac{\sigma_0^2}{\sigma_k^2} \boldsymbol{n}_k$$

Each block of observations gets a weight based on its contribution to the final solution

Data screening



Data screening



VCE on constraints

$$\boldsymbol{l}=\mathbf{A}\,\boldsymbol{x} \quad \text{with} \quad \mathbf{A}=\begin{bmatrix} orbit & gravity & PCA \\ \vdots & \vdots & \vdots \end{bmatrix}$$

$$\begin{bmatrix} \boldsymbol{l} \\ \vdots \\ \mathbf{0} \end{bmatrix} \rightarrow \mathbf{A}=\begin{bmatrix} orbit & gravity & PCA \\ \vdots & \vdots & \vdots \\ \mathbf{0} & \mathbf{0} & \mathbf{I} \end{bmatrix}$$

The appropriate constraint may be set through $\mathbf{P}$

Sets a weight for the constraint as

$$\mathbf{N}_k=\begin{bmatrix} \frac{\sigma_0^2}{\sigma_{constr}^2} & \\ & \ddots \end{bmatrix}$$

VCE:

$$r_k=n_{obs}-\frac{\sigma_0^2}{\sigma_k^2}\operatorname{tr}\left(\mathbf{N}_k\mathbf{N}^{-1}\right)$$

$$\sigma_k^2=\frac{\boldsymbol{e}_k^T\mathbf{P}_k\boldsymbol{e}_k}{r_k}$$

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

VCE on constraints - parenthesis

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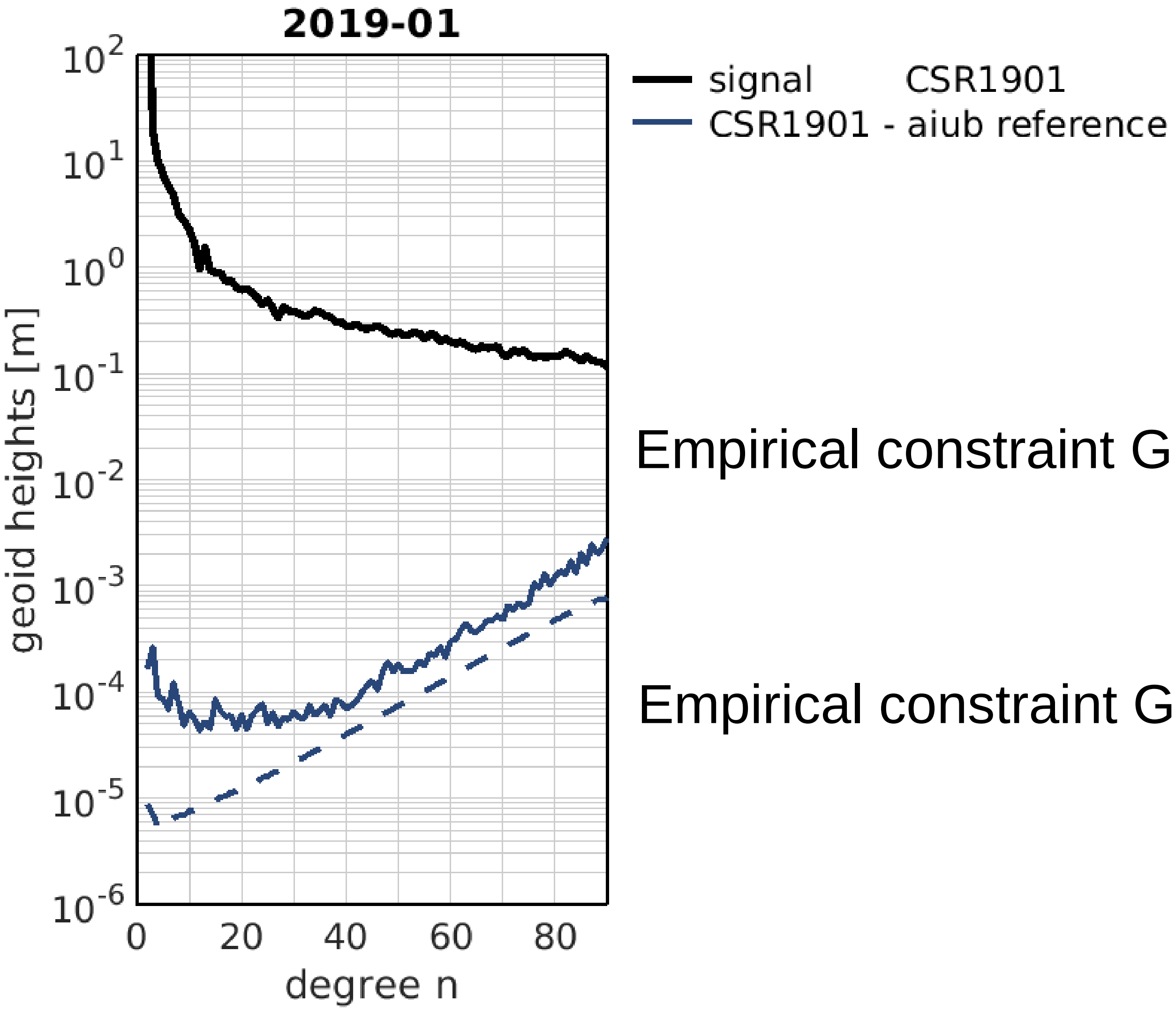
- Orbit Transformation (described in Beutler et al. 2010): instead of estimating parameters for GF1 & GF2 transform orbit parameters to:

$$\frac{GF1+GF2}{2}$$ → referring to the mean point in space between GF1 & GF2 (driven by GPS)

$$\frac{GF1-GF2}{2}$$ → referring to the difference between GF1 & GF2 (driven by K-band)

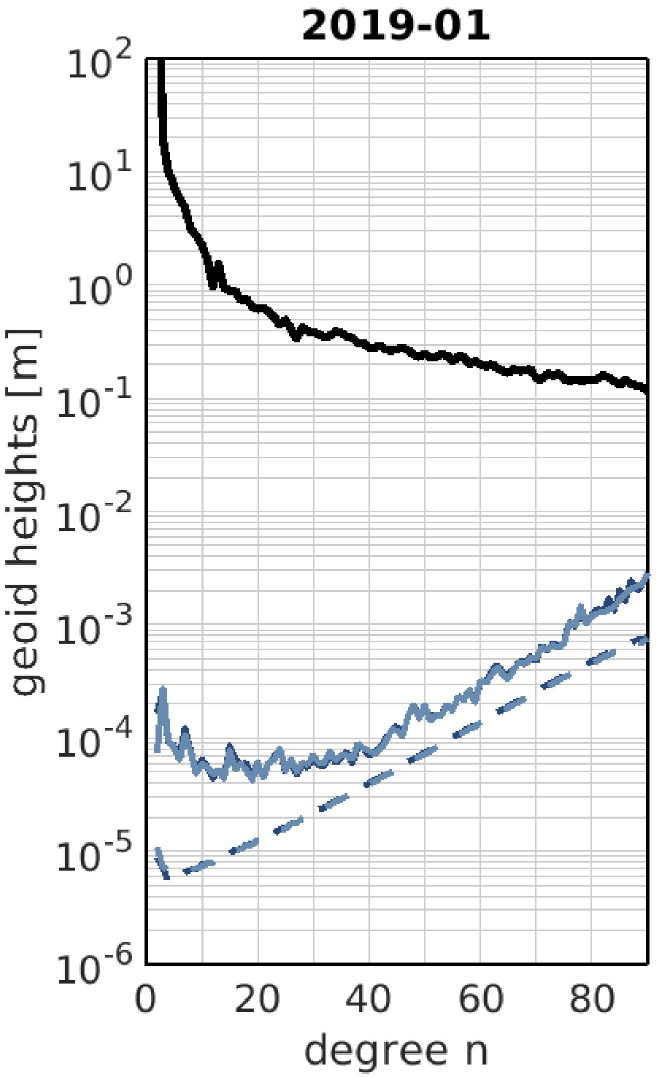
VCE on constraints - results



Empirical constraint GF1+GF2: $3 \cdot 10^{-10}\, m/s^2$

Empirical constraint GF1-GF2: $3 \cdot 10^{-11}\, m/s^2$

VCE on constraints - results



Empirical constraint GF1+GF2: $3 \cdot 10^{-10}\,\mathrm{m/s^2}$

VCE constraint GF1+GF2: $3.9 \cdot 10^{-10}\,\mathrm{m/s^2}$

Empirical constraint GF1-GF2: $3 \cdot 10^{-11}\,\mathrm{m/s^2}$

VCE constraint GF1-GF2: $1.6 \cdot 10^{-11}\,\mathrm{m/s^2}$

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VCE on constraints per axis

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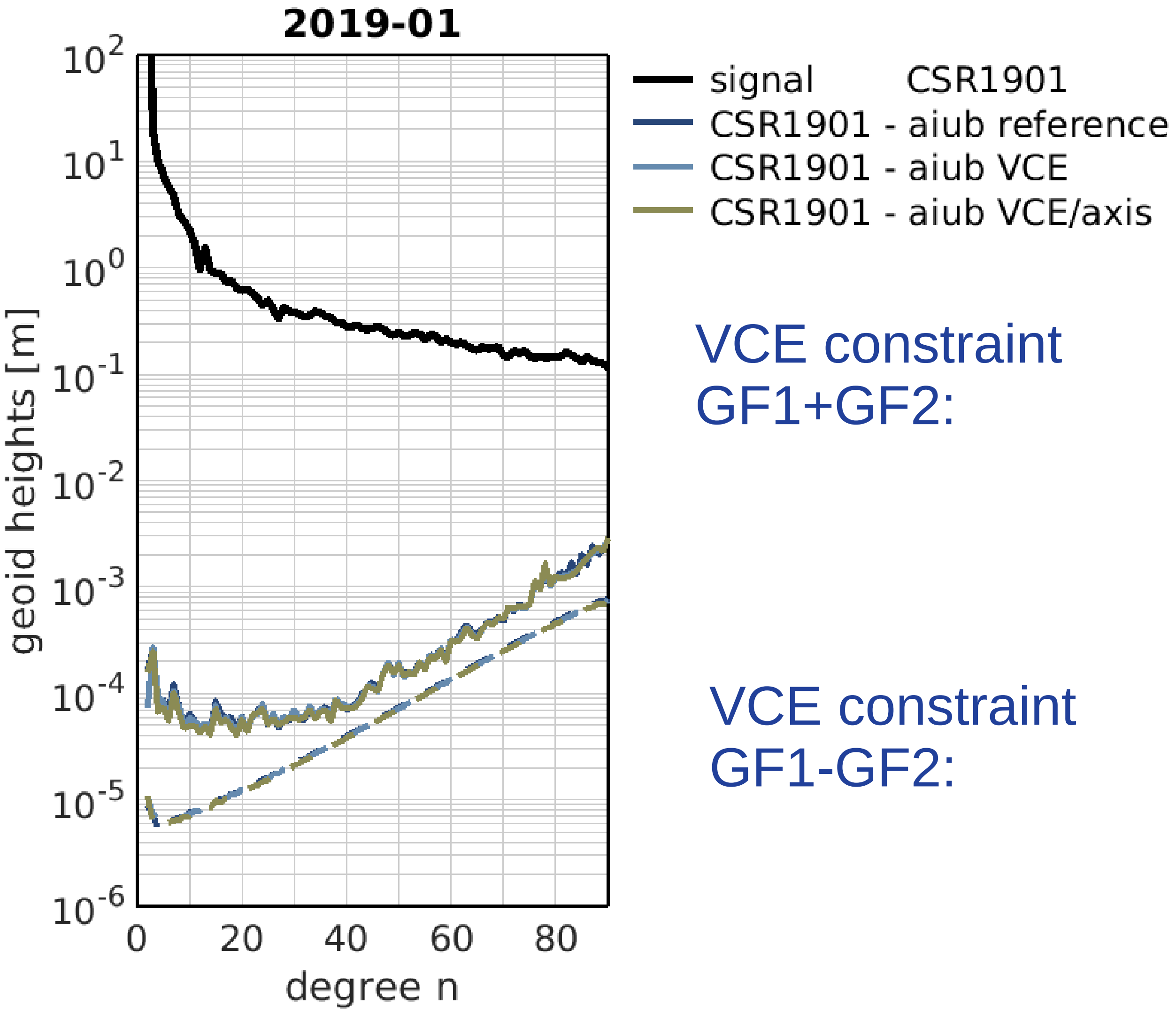

VCE constraint GF1+GF2:

$$\left.\begin{aligned} R&: 1.7\cdot 10^{-10}\,m/s^2 \\ A&: 6.7\cdot 10^{-11}\,m/s^2 \\ O&: 6.3\cdot 10^{-10}\,m/s^2 \end{aligned}\right\}\ \text{mean}: 2.9\cdot 10^{-10}\,m/s^2$$

VCE constraint GF1-GF2:

$$\left.\begin{aligned} R&: 3.0\cdot 10^{-11}\,m/s^2 \\ A&: 1.4\cdot 10^{-11}\,m/s^2 \\ O&: 1.3\cdot 10^{-10}\,m/s^2 \end{aligned}\right\}\ \text{mean}: 6\cdot 10^{-11}\,m/s^2$$

Conclusions

- Operational and up-to-date GRACE-FO timeseries
- Reasonbly low noise
- High weight in combination

- Confirm empirical constraining of PCA by VCE
- Extend modelling of parameter space

Thank you for your attention!