

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

Martin Lasser, Ulrich Meyer, Daniel Arnold, Adrian Jäggi

Astronomical Institute, University of Bern, Switzerland

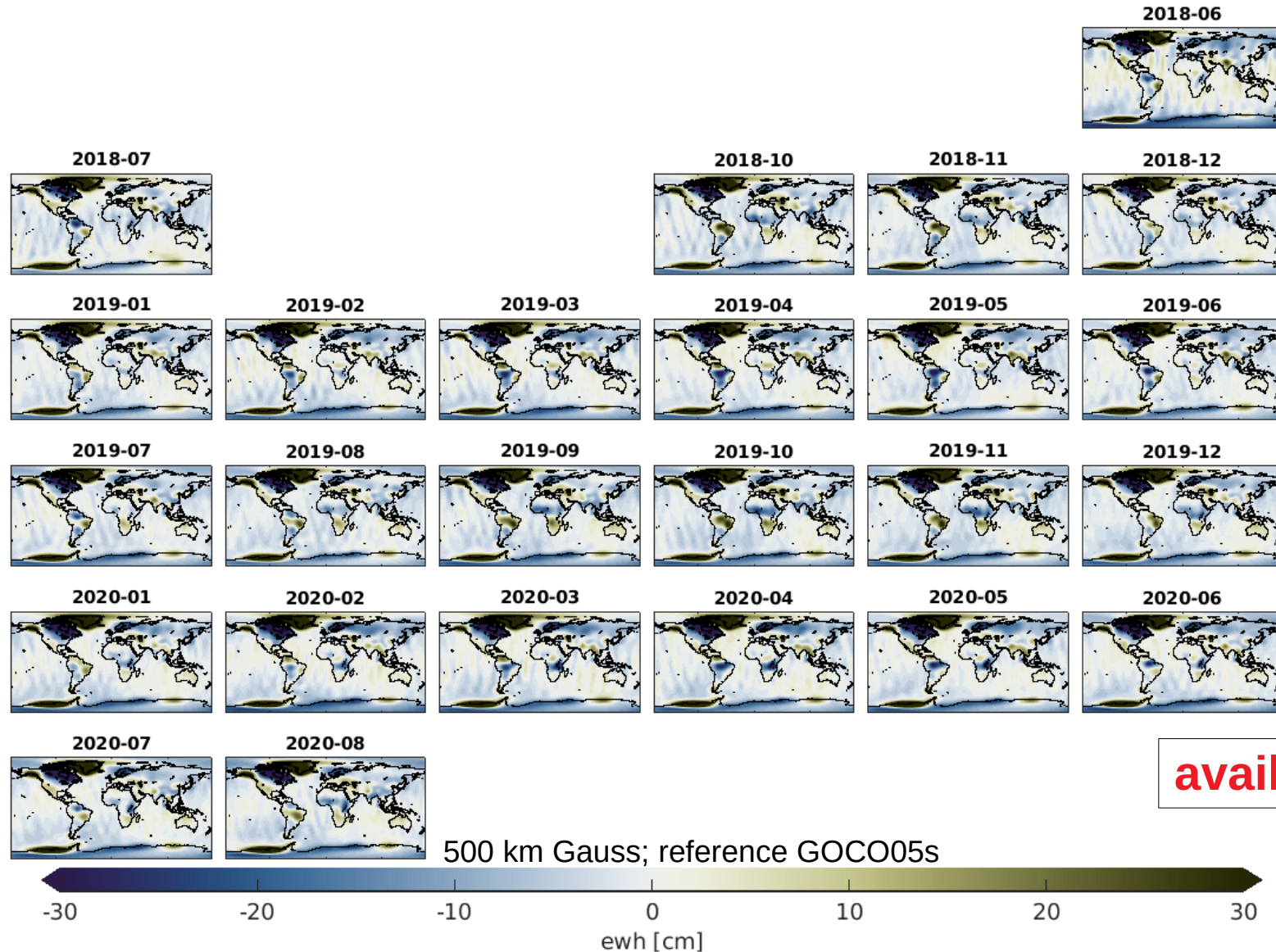
GRACE & GRACE-FO Science Team Meeting

Oct. 26-29, 2020

Online



Time series AIUB-GRACE-FO-operational



M. Lasser, U. Meyer, D. Arnold, A. Jäggi: Time-variable gravity field determination from GRACE-FO data at AIUB
GRACE & GRACE-FO Science Team Meeting, Oct. 26-19 2020, Online

Modelling

Parametrisation

6 initial conditions (daily)

accelerometer bias and scaling (daily)

15 min piecewise constant accelerations (PCA) (daily)

gravity field coefficients (monthly)

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

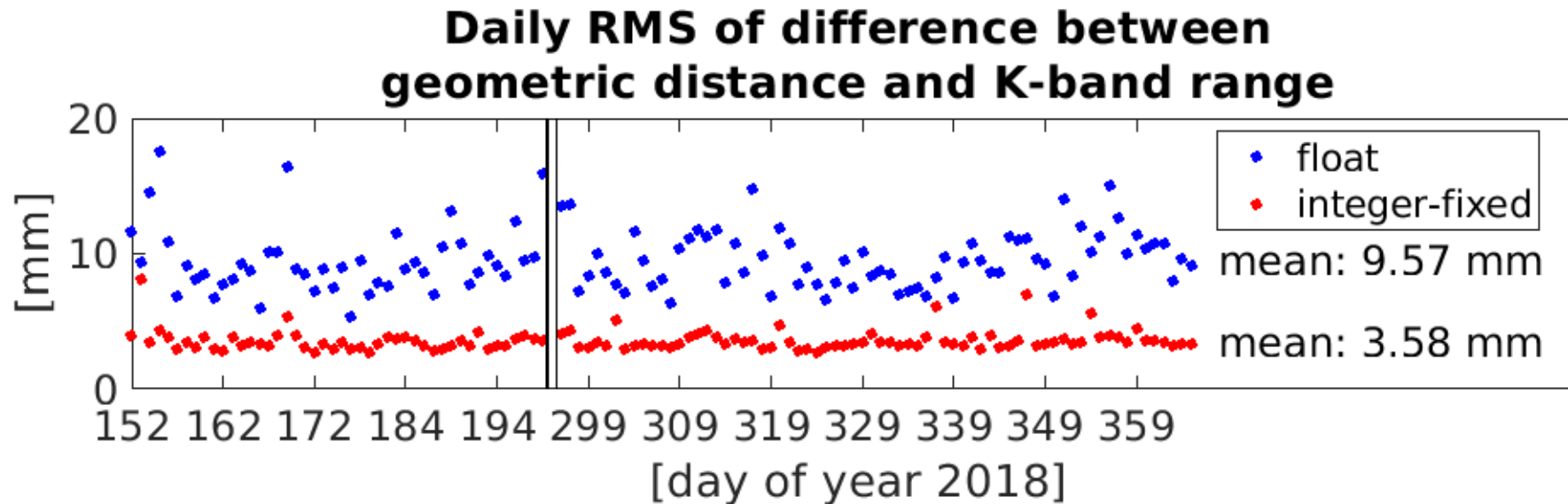
Modelling cont'd

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 & oceanic dealiasing	AOD RL06 (d/o=100)
Relativistic effects	IERS2010
Non-conservative forces	Accelerometer L1b (IfG)

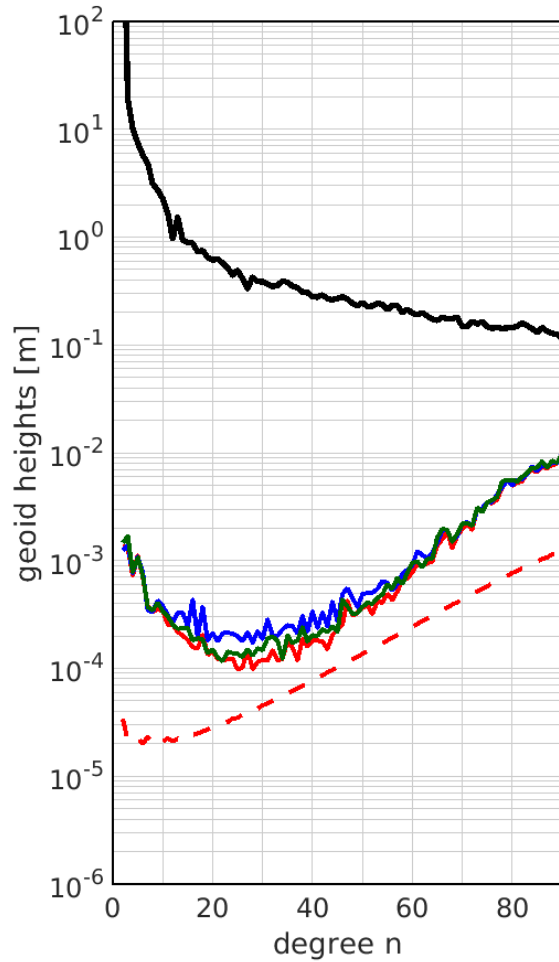
Kinematic positions

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



Individual arcs feature reduced position noise

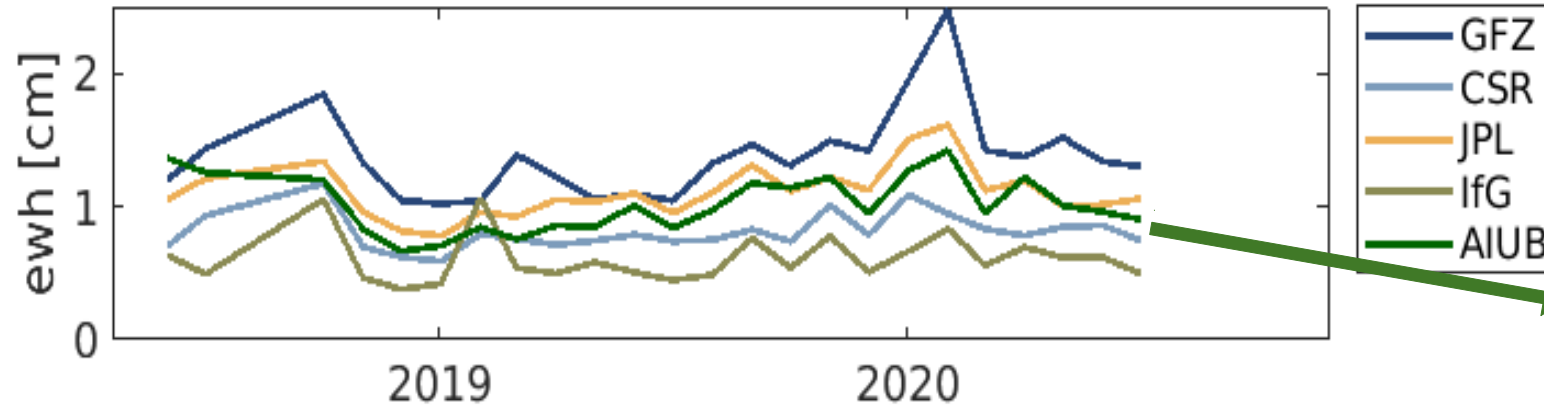
Influence of integer-fixed positions



- Reference: AIUB + downweight GPS by a factor of 10
- float + no downweighting of GPS
- integer-fix + no downweighting of GPS

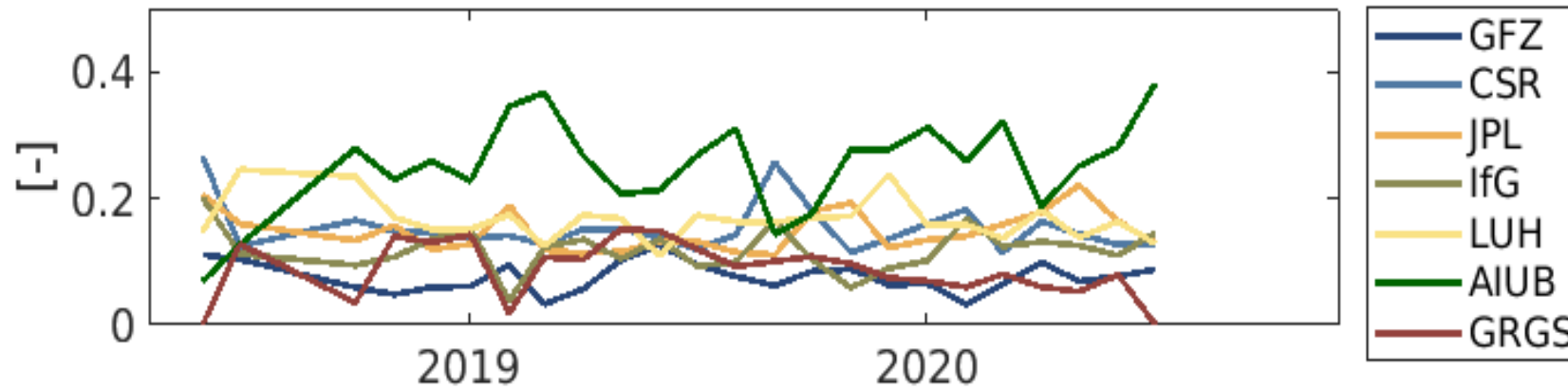
Performance

noise over the oceans

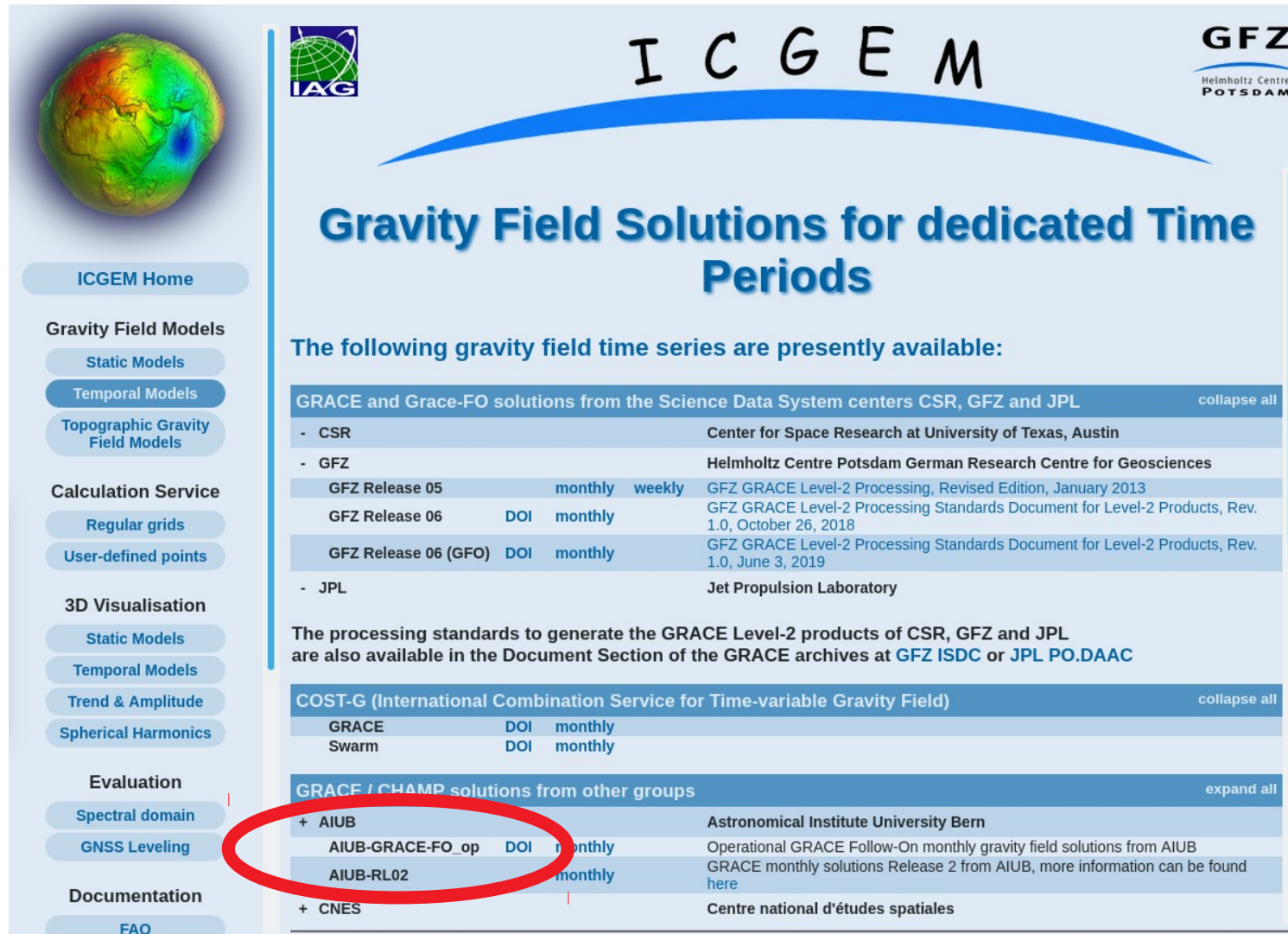


Large contribution from IfG-ACT!

VCE weights (normalised)



Level-2 product availability



The screenshot shows the ICGEM website interface. At the top, there is a globe on the left, the IAG logo, the ICGEM acronym in large letters, and the GFZ logo. The main heading is "Gravity Field Solutions for dedicated Time Periods". Below this, a text block states: "The following gravity field time series are presently available:". This is followed by a table listing various data sources and their processing details. A red circle highlights the AIUB entries in the table.

GRACE and Grace-FO solutions from the Science Data System centers CSR, GFZ and JPL					collapse all
-	CSR				Center for Space Research at University of Texas, Austin
-	GFZ				Helmholtz Centre Potsdam German Research Centre for Geosciences
	GFZ Release 05	monthly	weekly		GFZ GRACE Level-2 Processing, Revised Edition, January 2013
	GFZ Release 06	DOI	monthly		GFZ GRACE Level-2 Processing Standards Document for Level-2 Products, Rev. 1.0, October 26, 2018
	GFZ Release 06 (GFO)	DOI	monthly		GFZ GRACE Level-2 Processing Standards Document for Level-2 Products, Rev. 1.0, June 3, 2019
-	JPL				Jet Propulsion Laboratory
The processing standards to generate the GRACE Level-2 products of CSR, GFZ and JPL are also available in the Document Section of the GRACE archives at GFZ ISDC or JPL PO.DAAC					
COST-G (International Combination Service for Time-variable Gravity Field)					collapse all
	GRACE	DOI	monthly		
	Swarm	DOI	monthly		
GRACE / CHAMP solutions from other groups					expand all
+	AIUB				Astronomical Institute University Bern
	AIUB-GRACE-FO_op	DOI	monthly		Operational GRACE Follow-On monthly gravity field solutions from AIUB
	AIUB-RL02		monthly		GRACE monthly solutions Release 2 from AIUB, more information can be found here
+	CNES				Centre national d'études spatiales

Observation data processing

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

$$\begin{bmatrix} l_1 \\ l_2 \\ \vdots \\ l_n \end{bmatrix}$$

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

$$\rightarrow \quad \mathbf{N}_k = (\mathbf{A}_k^T \mathbf{P}_k \mathbf{A}_k)^{-1} \quad \text{and} \quad \mathbf{n}_k = \mathbf{A}_k^T \mathbf{P}_k l_k \quad \rightarrow \quad \hat{x} = \left(\sum_{k=1}^n \mathbf{N}_k \right)^{-1} \sum_{k=1}^n \mathbf{n}_k$$

Observation data weighting: VCE

l_1
 l_2
 \vdots
 l_n

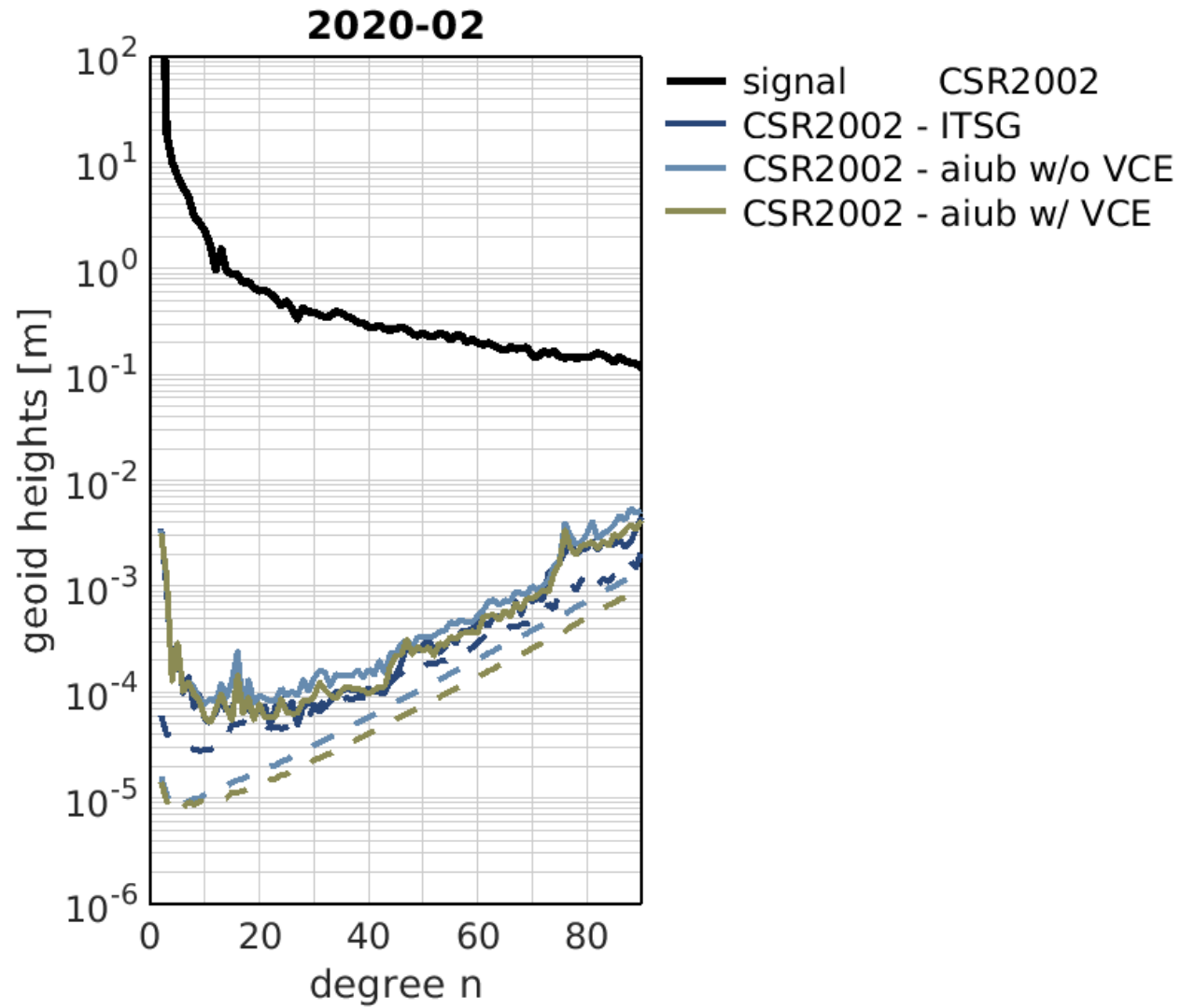
VCE:

$$\left. \begin{aligned} r_k &= n_{obs} - \frac{\sigma_0^2}{\sigma_k^2} \text{tr}(\mathbf{N}_k \mathbf{N}^{-1}) \\ \sigma_k^2 &= \frac{\mathbf{e}_k^T \mathbf{P}_k \mathbf{e}_k}{r_k} \end{aligned} \right\}$$

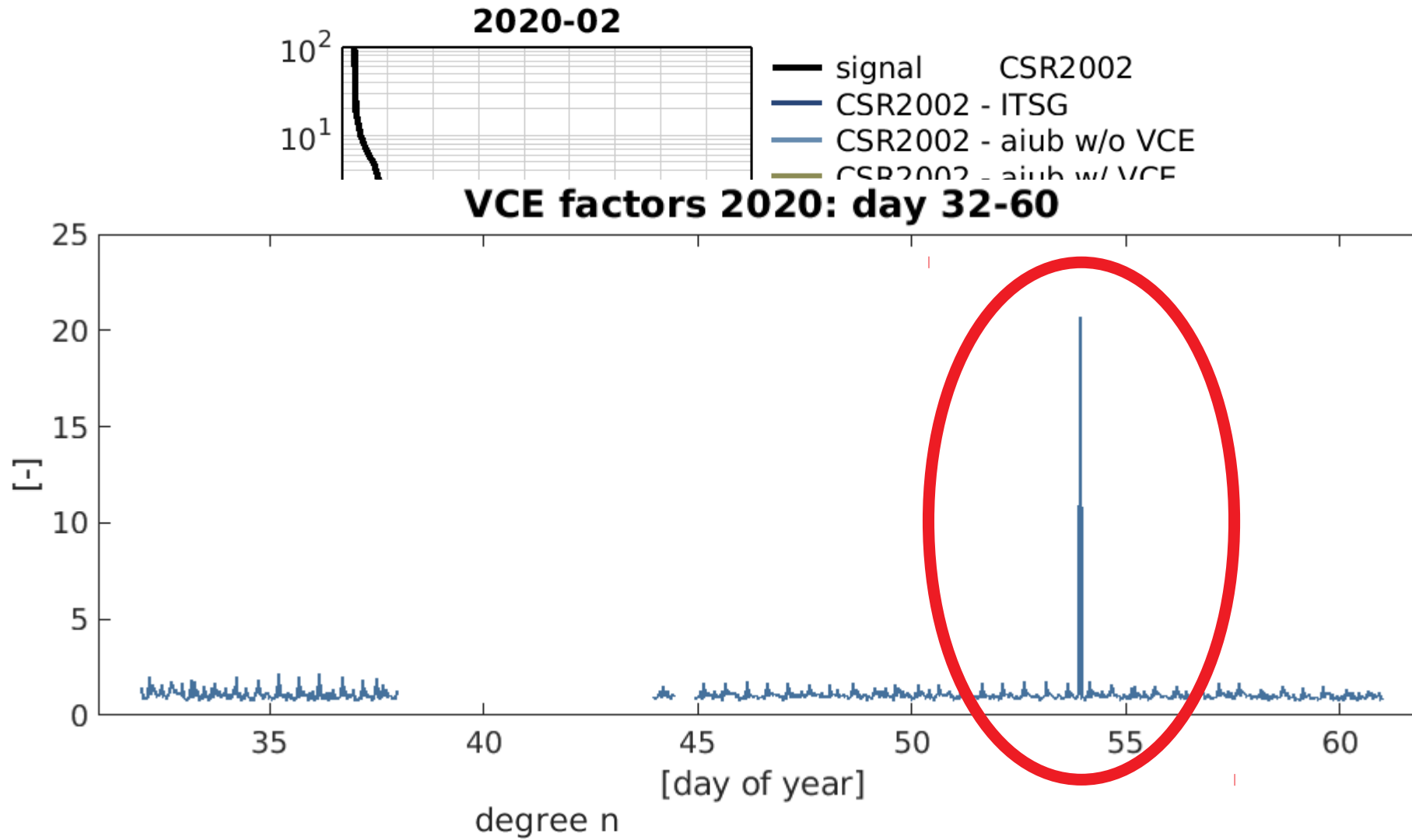
$$\hat{\mathbf{x}} = \left(\sum_{k=1}^n \frac{\sigma_0^2}{\sigma_k^2} \mathbf{N}_k \right)^{-1} \sum_{k=1}^n \frac{\sigma_0^2}{\sigma_k^2} \mathbf{n}_k$$

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

Data screening



Data screening



VCE on constraints

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

VCE:

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

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

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

$$\begin{bmatrix} l \\ \vdots \\ \mathbf{0} \end{bmatrix}$$

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

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

Sets a weight for the constraint as

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

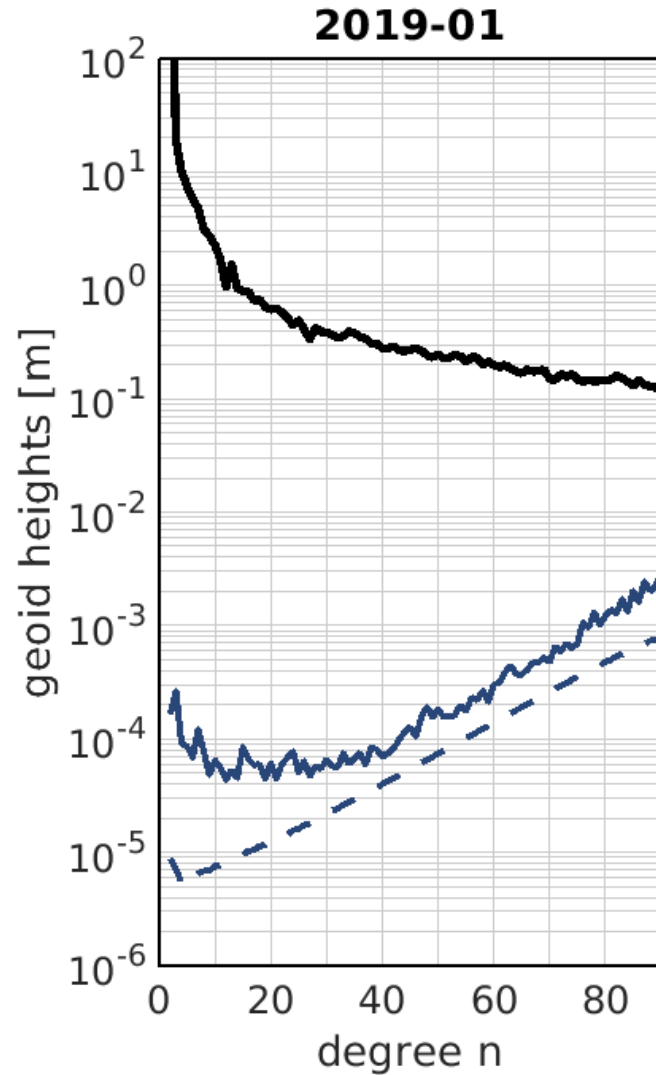
VCE on constraints - parenthesis

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

$$\frac{GF\ 1 + GF\ 2}{2} \rightarrow \text{referring to the mean point in space between GF1 \& GF2 (driven by GPS)}$$

$$\frac{GF\ 1 - GF\ 2}{2} \rightarrow \text{referring to the difference between GF1 \& GF2 (driven by K-band)}$$

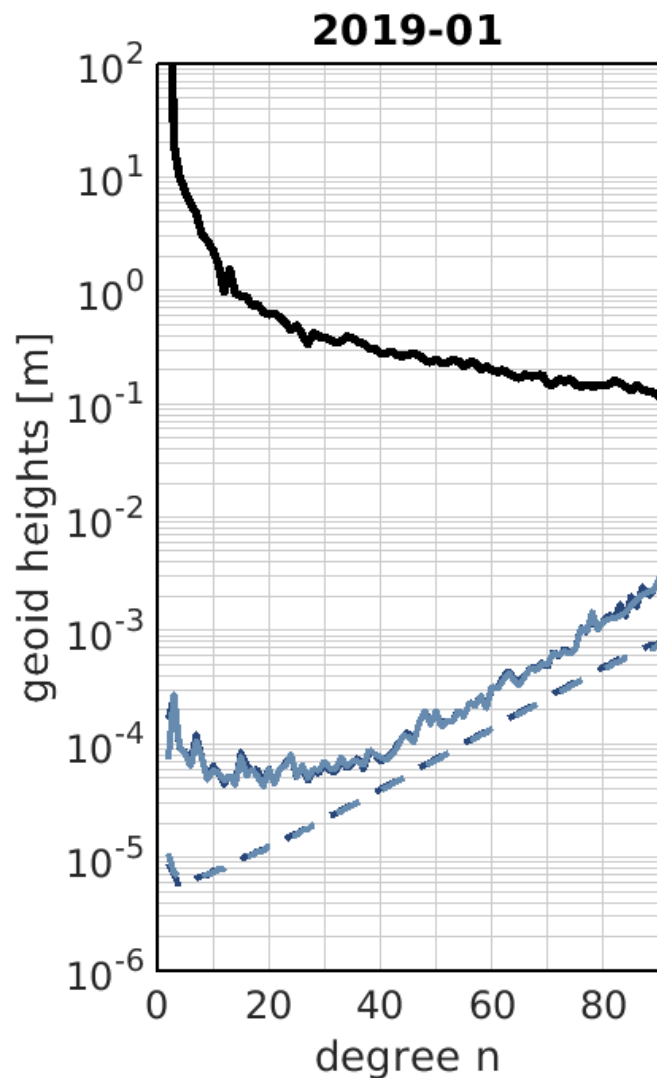
VCE on constraints - results



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

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

VCE on constraints - results



— signal CSR1901
— CSR1901 - aiub reference
- - CSR1901 - aiub VCE

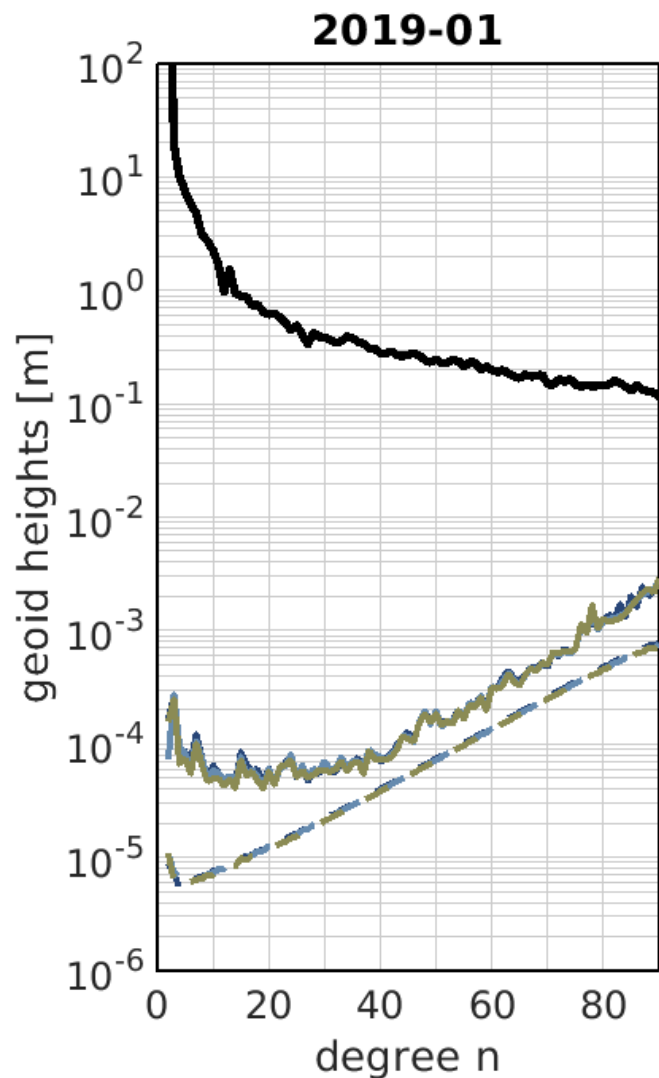
Empirical constraint GF1+GF2: $3 \cdot 10^{-10} \text{ m/s}^2$

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

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

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

VCE on constraints per axis



— signal CSR1901
 — CSR1901 - aiub reference
 - - CSR1901 - aiub VCE
 — CSR1901 - aiub VCE/axis

VCE constraint
GF1+GF2:

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

VCE constraint
GF1-GF2:

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

Conclusions

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

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

Thank you for your attention!