Processing of GRACE-FO satellite-to-satellite tracking data using the GRACE-SIGMA software

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Gravity field recovery at IfE

- Monthly gravity potential solutions from GRACE-FO Level 1B data are computed at the Institute of Geodesy (IfE) / Leibniz University Hannover (LUH)
- The gravity field is recovered using the all-MATLAB software “GRACE-SIGMA“ that was recently developed at our institute ***[1,2]***
- The monthly GRACE-FO solutions are the outcome of a common dynamic orbit and gravity field determination (variational equations approach)

Processing specifics

Two-step approach

In an orbit pre-adjustment, appropriate satellite-specific parameters (satellite states and accelerometer calibration parameters) are estimated. These parameters are used as initial values in the main adjustment where the gravity field parameters are estimated along with the orbit parameters in one iteration.

Numerical integration

Numerical integration of the satellite ephemerides and the state transition and sensitivity matrices is accomplished with a modified Gauss-Jackson integrator using a 5 seconds integration step size.

Observations

As observations for the parameter estimation, K band range rates (5 seconds) are combined with GNV1B positions (30 seconds). First experimental test runs were made with kinematic orbits instead of reduced-dynamic GNV1B orbits.

Weighting

The two observation groups (positions and K band range rates) are weighted using a fixed relative technique-specific ratio of 1/1E10.

Constraints and regularization

The solutions are not regularized. All parameters, including satellite-specific parameters, are estimated without any constraints.

Force modeling

Effect	Pre-EGU version	Updates
Gravity field	GIF48 (d/o 300) [3]	GOCO06s, static: d/o 300, [4] time-variable: d/o 200
Direct tides	Moon and Sun, ephemerides: DE405 [5]	+ Mercury, Venus, Mars, Jupiter, Saturn, J2 for the Moon, ephemerides: DE430 [6]
Solid Earth tides	IERS Conventions 2010 [7]	-
Ocean tides	EOT11a (d/o 80) [8]	FES2014b (d/o 180) [9]
Solid Earth pole tides	IERS Conventions 2010	linear mean pole
Ocean pole tides	IERS Conventions 2010 (d/o 60)	linear mean pole, (d/o 180)
Relativistic	IERS Conventions 2010	-
Non-tidal	AOD1B RL06 (d/o: 180) [10]	-
Atmospheric tides	Biancale and Bode, N1, seasonal means [11]	AOD1B RL06 (d/o 180)

Parametrizations

- The recent evolution of the LUH GRACE-FO gravity fields, starting from the first preliminary gravity field solutions, will be presented in the next slides

- **Pre-EGU**: Approach was used for preliminary GRACE-FO results presented at conferences starting from IUGG 2019
- **COST-G***: Based on this parametrization solutions for the first preliminary COST-G combination were computed
- **Current best**: This parametrization is used for the most recent set of gravity field solutions

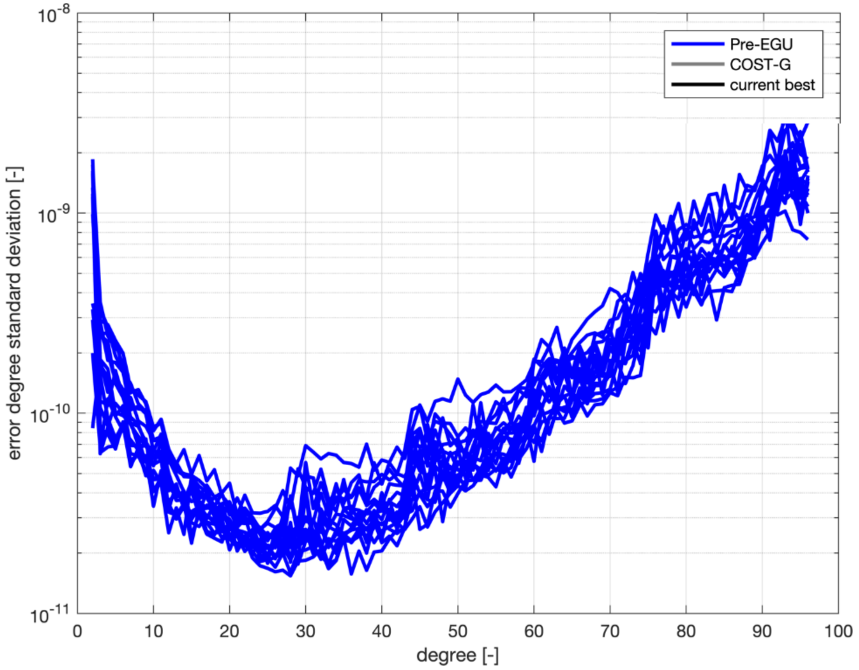
* Combination Service for time-variable Gravity Fields

Parametrization: Pre-EGU

* but with updated force models

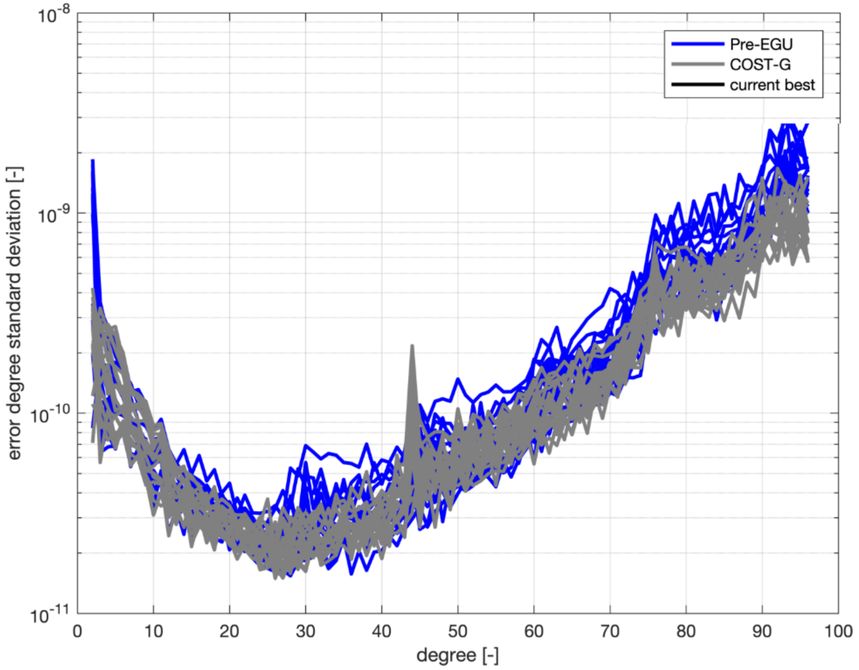
arc length	3 hours
local parameters	- initial states - accelerometer biases - accelerometer scales (diagonal elements) - empirical KBRR parameters: ***[12]*** linear: 1.5 hours periodic: 3 hours
global parameters	- gravity potential d/o 96

- Error degree standard deviations are computed w.r.t. to the model GOCO06s
- 2018/06 – 2020/01



Parametrization: COST-G

arc length	1.5 hours
local parameters	- initial states - accelerometer biases - empirical KBRR parameters: linear: 0.75 hours periodic: 1.5 hours
global parameters	- gravity potential d/o 96 - accelerometer scales (full matrix) ***[13]***

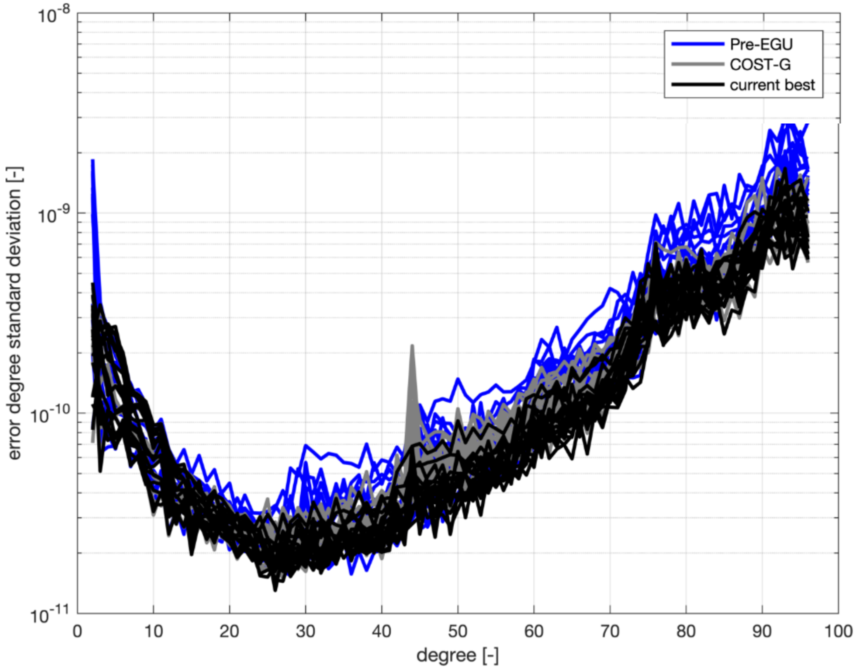


- improvements for (almost) the whole spectrum
- C20 coefficient improved considerably
- parametrization sensitive to orbital resonance (degree 45)

Parametrization: Current best

arc length	1.5 hours
local parameters	- initial states - accelerometer biases - empirical KBRR parameters: linear: 1.5 hours periodic: 1.5 hours
global parameters	- gravity potential d/o 96 - accelerometer scales (full matrix)

- by setting the resolution of the linear empirical KBRR parameters to 90 min, a large improvement around degree 45 can be seen



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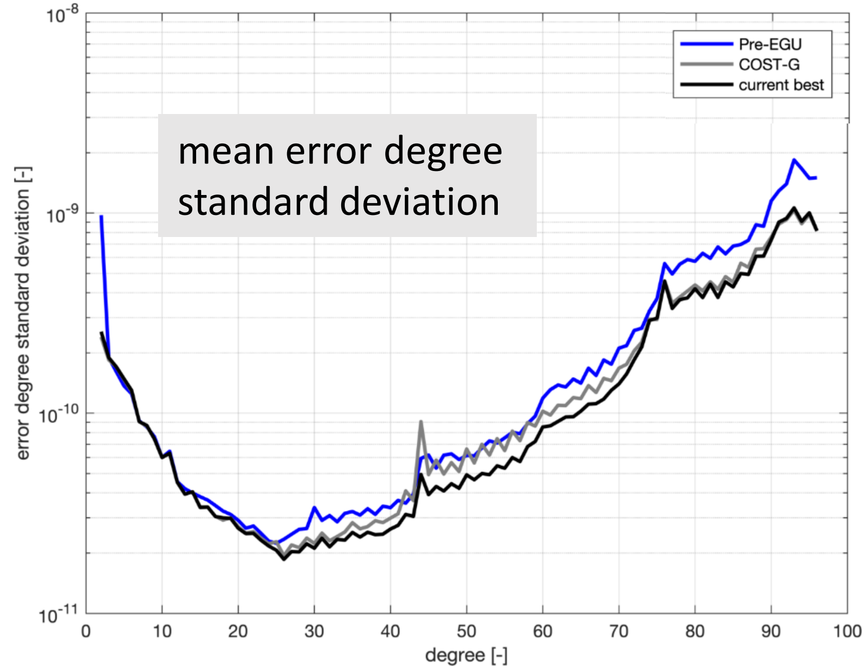
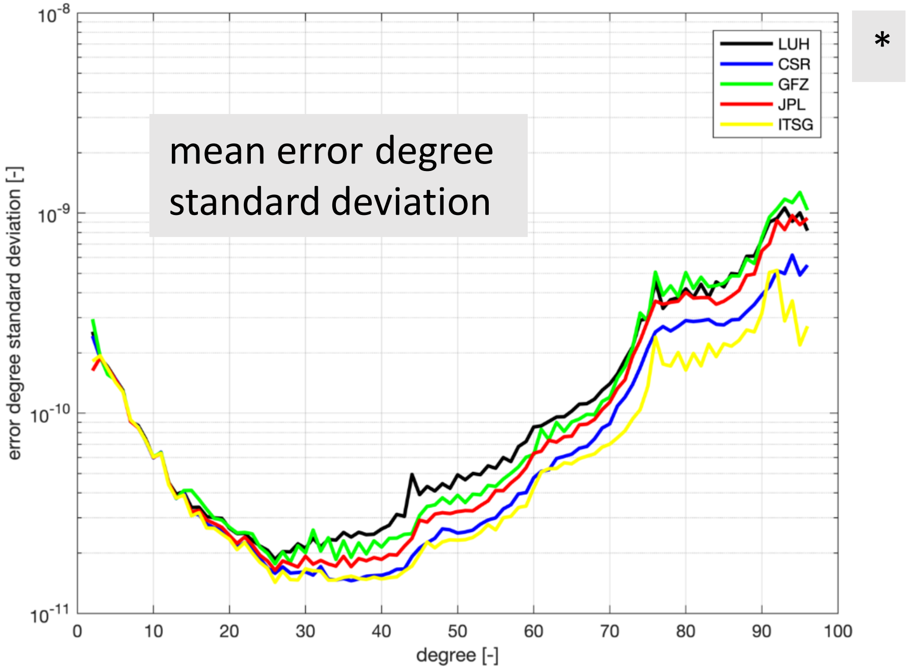


Comparison to selected analysis centers

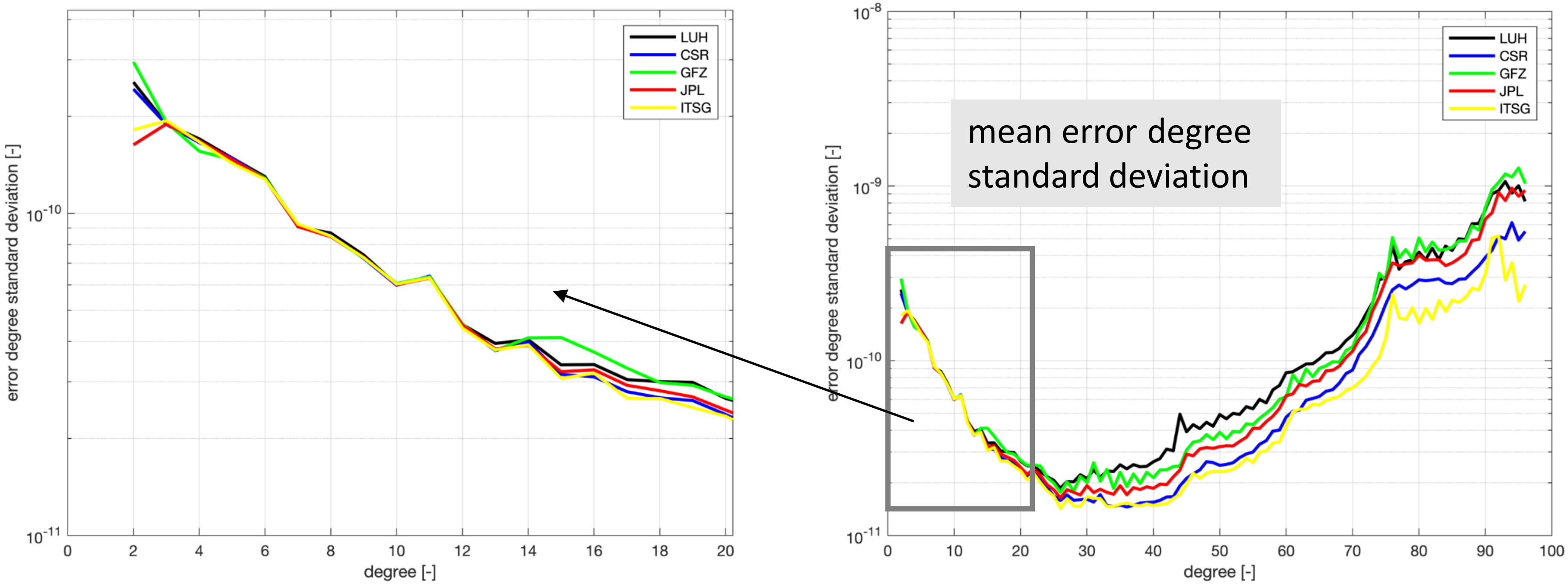
arc length	1.5 hours
local parameters	- initial states - accelerometer biases - empirical KBRR parameters: linear: 1.5 hours periodic: 1.5 hours
global parameters	- gravity potential d/o 96 - accelerometer scales (full matrix)

- resonance is still more striking compared to other analysis centers
- but comparable low and very high degrees



*LUH = current best

Comparison to selected analysis centers



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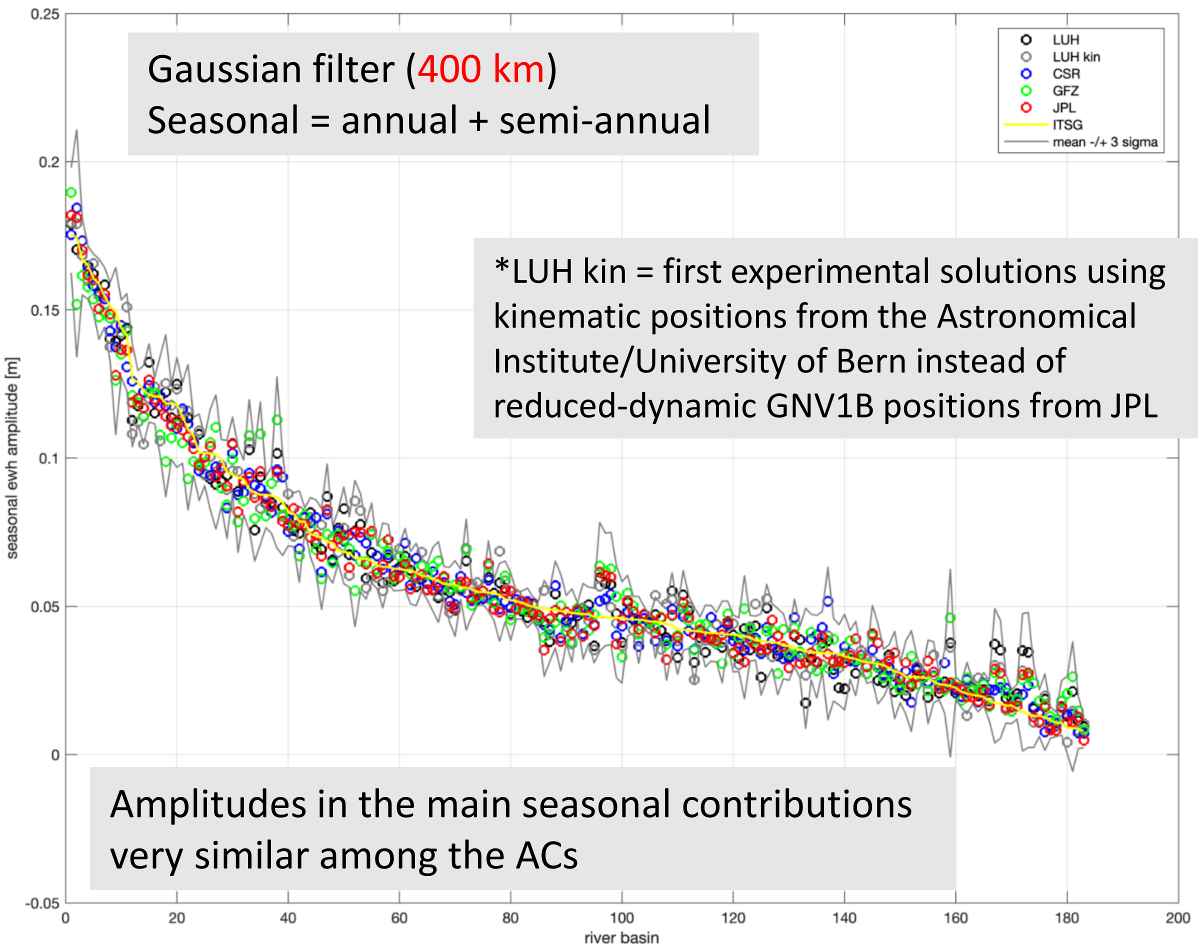
Equivalent water height - Seasonal amplitudes of river basins



Gaussian filter (400 km)
Seasonal = annual + semi-annual

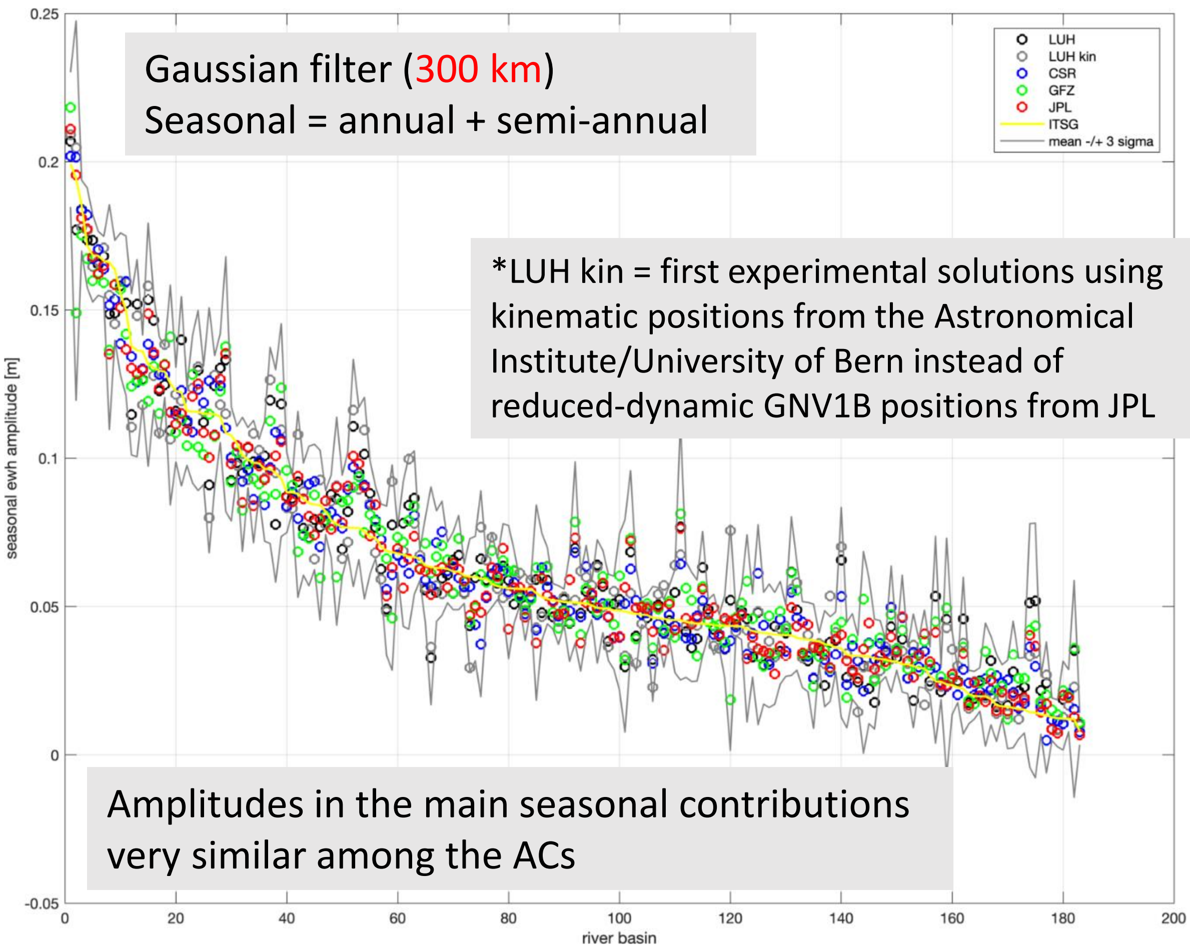
*LUH kin = first experimental solutions using kinematic positions from the Astronomical Institute/University of Bern instead of reduced-dynamic GNV1B positions from JPL

Amplitudes in the main seasonal contributions very similar among the ACs

- In order to roughly assess the similarity of signal amplitudes, we compute **basin averages for equivalent water heights** (EWH) of around 180 river basins
- As a reference model, the mean of CSR, GFZ, JPL and ITSG solutions (until 2020-01) is subtracted
- C20 as well as C30 coefficients are replaced by SLR values, as recommended
- Trend, annual and semi-annual term is fitted to the EWH values of each river basin

Equivalent water height - Seasonal amplitudes of river basins

Gaussian filter (300 km)
Seasonal = annual + semi-annual



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Equivalent water height - Residual signal

- In order to roughly assess the goodness of the fit, we subtract the estimated model (trend, annual and semi-annual term) from the river basin EWH values
- For each river basin and analysis center the rms of the residuals is computed
- The average of these rms residuals over all river basins is shown in the following table for Gaussian filter with 400 and 300 km radius

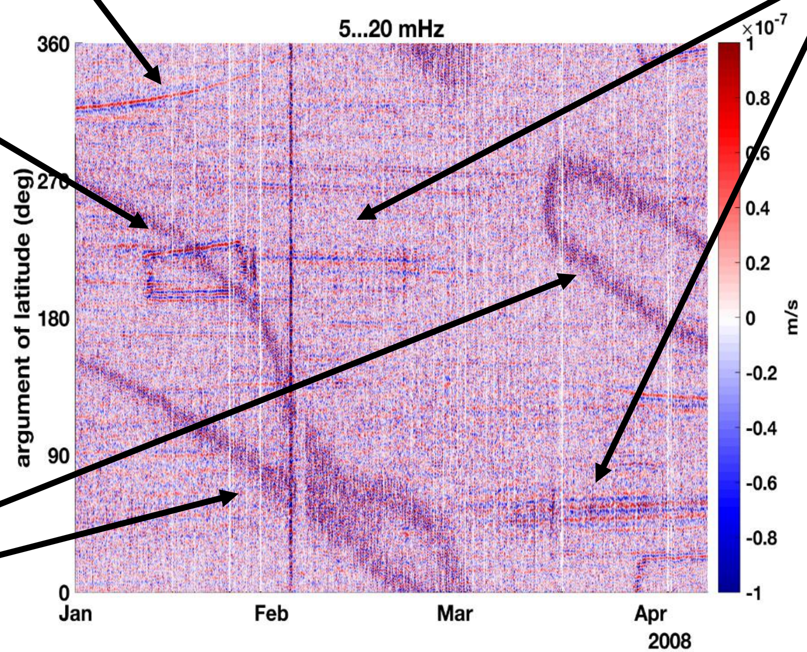
	LUH	LUH kin	CSR	GFZ	JPL	ITSG
400 km	1.67 cm	1.76 cm	1.48 cm	1.81 cm	1.55 cm	1.43 cm
300 km	2.34 cm	2.55 cm	1.87 cm	2.46 cm	2.07 cm	1.83 cm

Typical GRACE KBRR residuals 5 to 20 mHz bandpass filtered

shadow entry

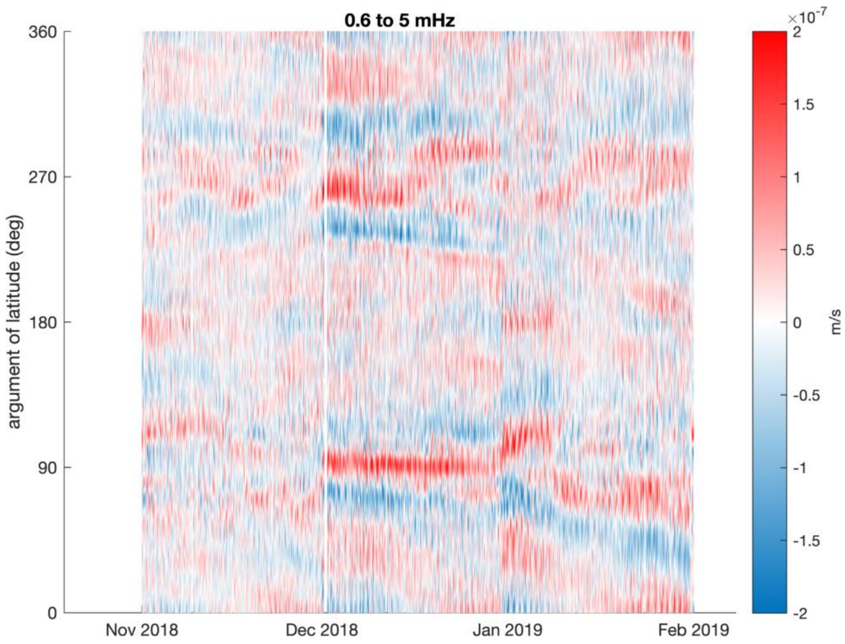
bands related to SCA head

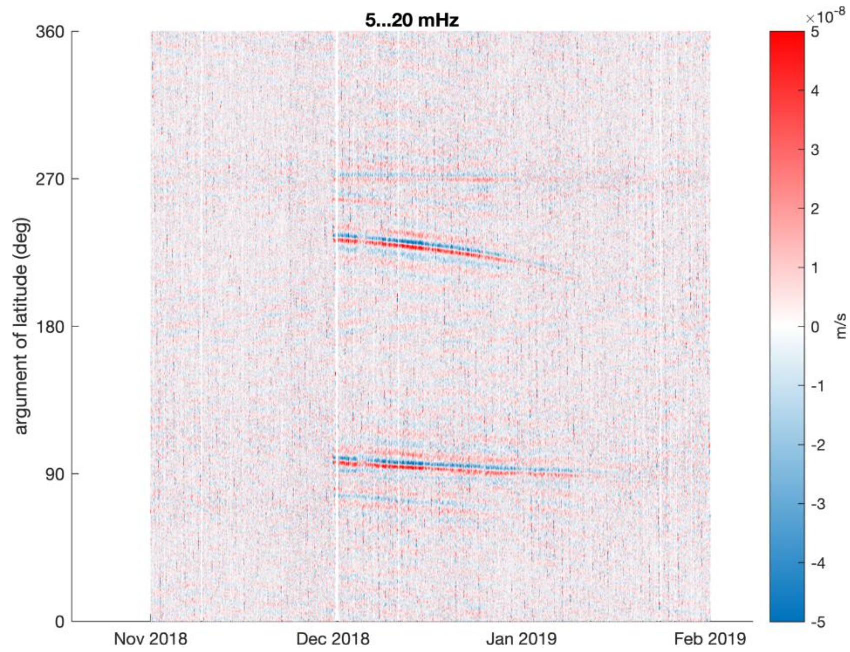
KBR SNR drop baffle related



KBR SNR drop frequency related

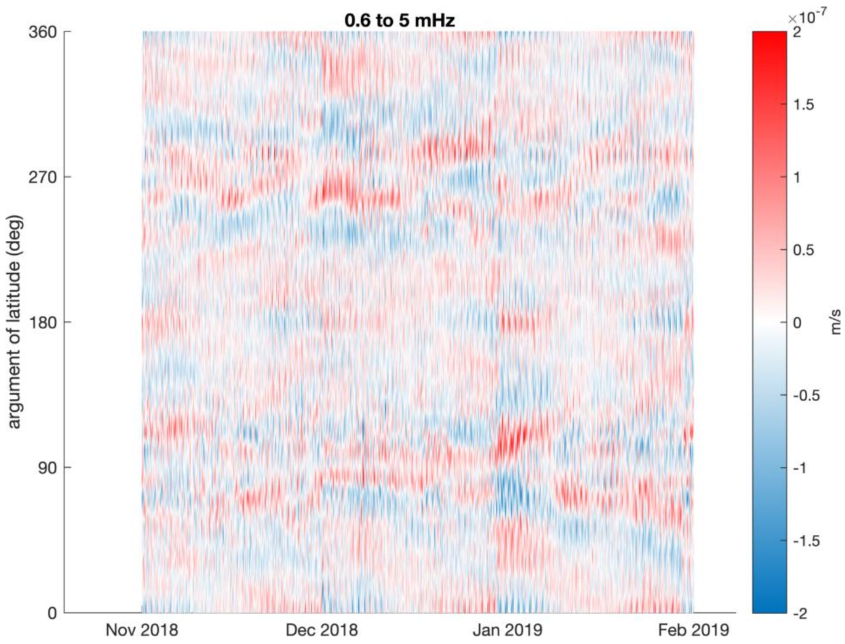
Typical GRACE-FO KBRR residuals
5 to 20 mHz bandpass filtered
0.6 to 5 mHz bandpass filtered

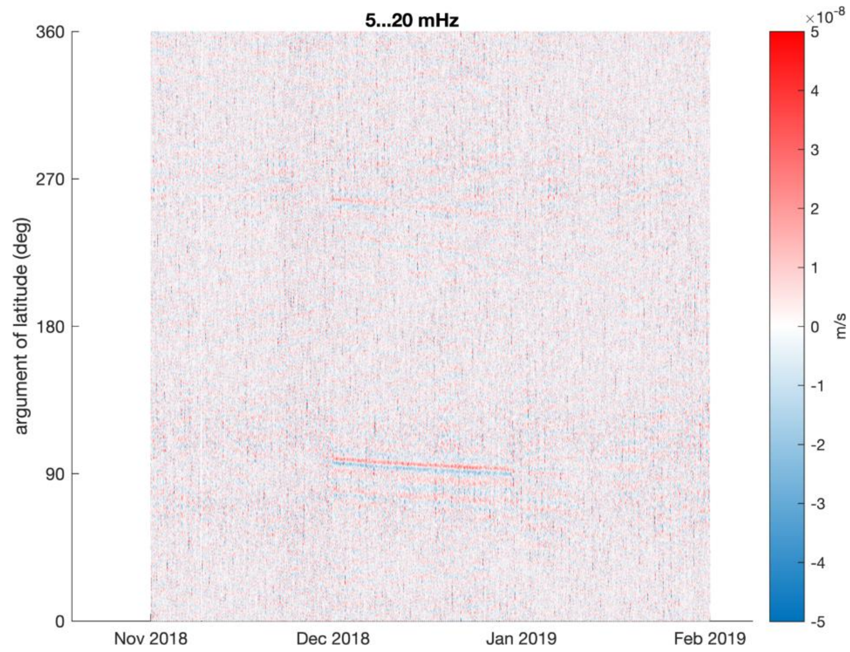




Pre-EGU
parametrization

Typical GRACE-FO KBRR residuals
5 to 20 mHz bandpass filtered
0.6 to 5 mHz bandpass filtered





Current best parametrization

Summary and future plans

- Current status of gravity field recovery from GRACE-FO data at Institute of Geodesy/Leibniz University Hannover was shown
- In terms of error degree standard deviations, the current LUH solutions are close to the solutions of GFZ
- The signal content is similar among the analysis centers
- Testing of different parametrizations and improvements in the processing chain are ongoing
- Combination of microwave and laser ranging measurements is foreseen in near future

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