Residual Ocean Tide Signal in GRACE(-FO) Range-Rate Post-Fit Residuals

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A – Abstract

- Ocean tide model imperfections are one of the major uncertainty factors in gravity field recovery. Unmodeled signal can alias into level-2 gravity field products and be interpreted as real signal, e.g. as ice mass loss. An accurate understanding of the ocean tide model imperfections (on spectral and spatial level) is therefore not only important for current, but also for future gravity field missions.
- For this contribution, we analyzed 20+ years of GRACE(-FO) K-band range-rate post-fit residuals for residual ocean tide signal. The post-fit residuals are obtained as part of the gravity field estimation of monthly solutions. We low pass filter and differentiate range-rate post-fit residuals to obtain residual range-accelerations. Obtained residual range-accelerations are assigned to 5x5 degree grid cells and Lomb-Scargle periodograms for each cell are computed.
- An analysis of the periodograms reveals peaks at frequencies of ocean tide constituents. The peaks with the largest spectral amplitude can be found at frequencies of the major constituents (O1, M2, K1). In total around 30 constituents are detectable, among them also compound tides and degree-3 tides.

B – K-band range-rate post-fit residuals

We analyze GRACE(-FO) K-band range-rate post-fit residuals covering the time span 2002-2022 (ca. 100 million data records). The 5 seconds sampling residuals are obtained as part of the gravity field recovery process of monthly solutions **[1]**. For orbit propagation (state-of-the-art) models were used, among them FES2014b **[2]** (ocean tides) and AOD1B-RL06 **[3]** (non-tidal atmosphere and ocean, atmospheric tides).

We define GRACE K-band post-fit range-rate residuals as follows:

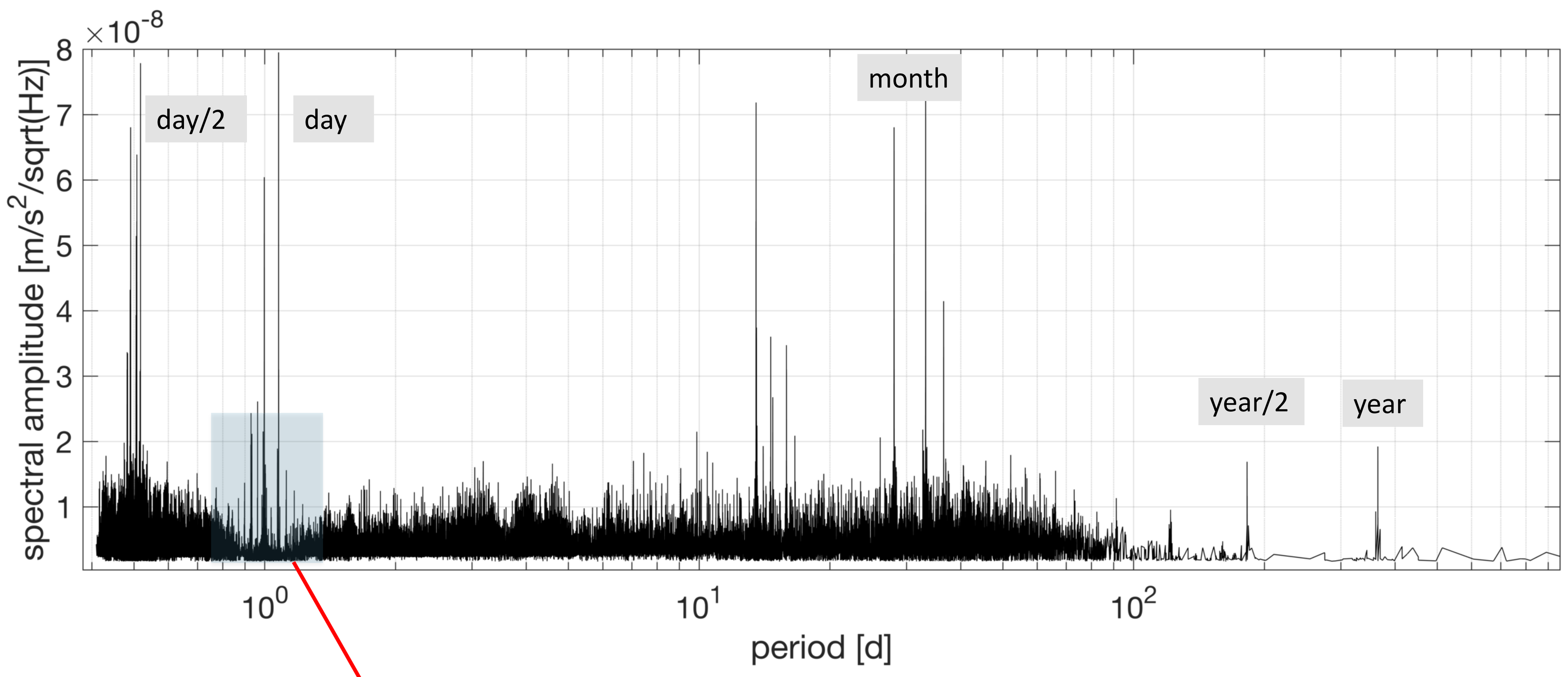
$$\hat{\mathbf{v}} = \mathbf{A}_{\sim \mathrm{AB}}\,\hat{\mathbf{x}}_{\sim} + \mathbf{A}_{\oplus \mathrm{AB}}\,\hat{\mathbf{x}}_{\oplus} - \mathbf{l}_{\mathrm{AB}}$$

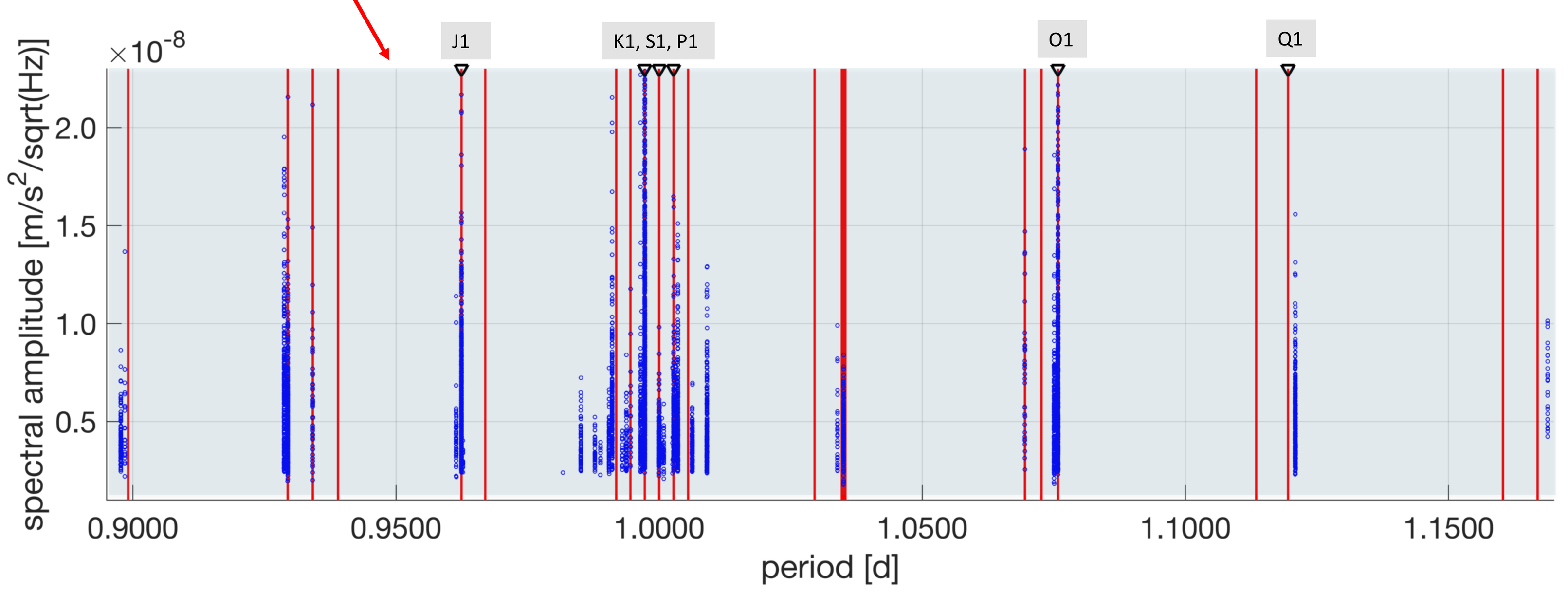
with $\hat{\mathbf{v}}$: estimated K-band range-rate post-fit residuals, $\mathbf{A}_{\sim \mathrm{AB}}$: design matrix of arc specific parameters, $\mathbf{A}_{\oplus \mathrm{AB}}$: design matrix of global parameters, $\hat{\mathbf{x}}_{\sim}$: estimated arc specific parameters (initial states, accelerometer bias, empirical parameters), $\hat{\mathbf{x}}_{\oplus}$: estimated global parameters (spherical harmonic coefficients, accelerometer scale matrices), and $\mathbf{l}_{\mathrm{AB}}$: reduced K-band range-rates.

C – Spectral analysis of post-fit residuals

1: Low pass filtering of post-fit range-rate residuals
2: Numerical differentiation of low pass filtered post-fit range-rate residuals
3: Assigning obtained residual range-accelerations to 5x5 degree grid cells
4: Lomb-Scargle periodogram of time series at each grid cell
5: Scanning each periodogram for amplitudes larger than 3 sigma
6: Plot all found amplitudes in a common plot (→ D, upper figure)

D – Amplitudes > 3 sigma





Upper figure: Amplitudes in a grid cell larger than 3 times the standard deviation w.r.t. the mean. Due to the irregular sampling of the (residual) signal by the GRACE(-FO) satellites, the figure contains redundant information in terms of spectral replicas.
Bottom figure: Zoom view of post-processed diurnal band. Red lines depict tidal periods; black down triangle: constituent is part of the applied ocean tide model.

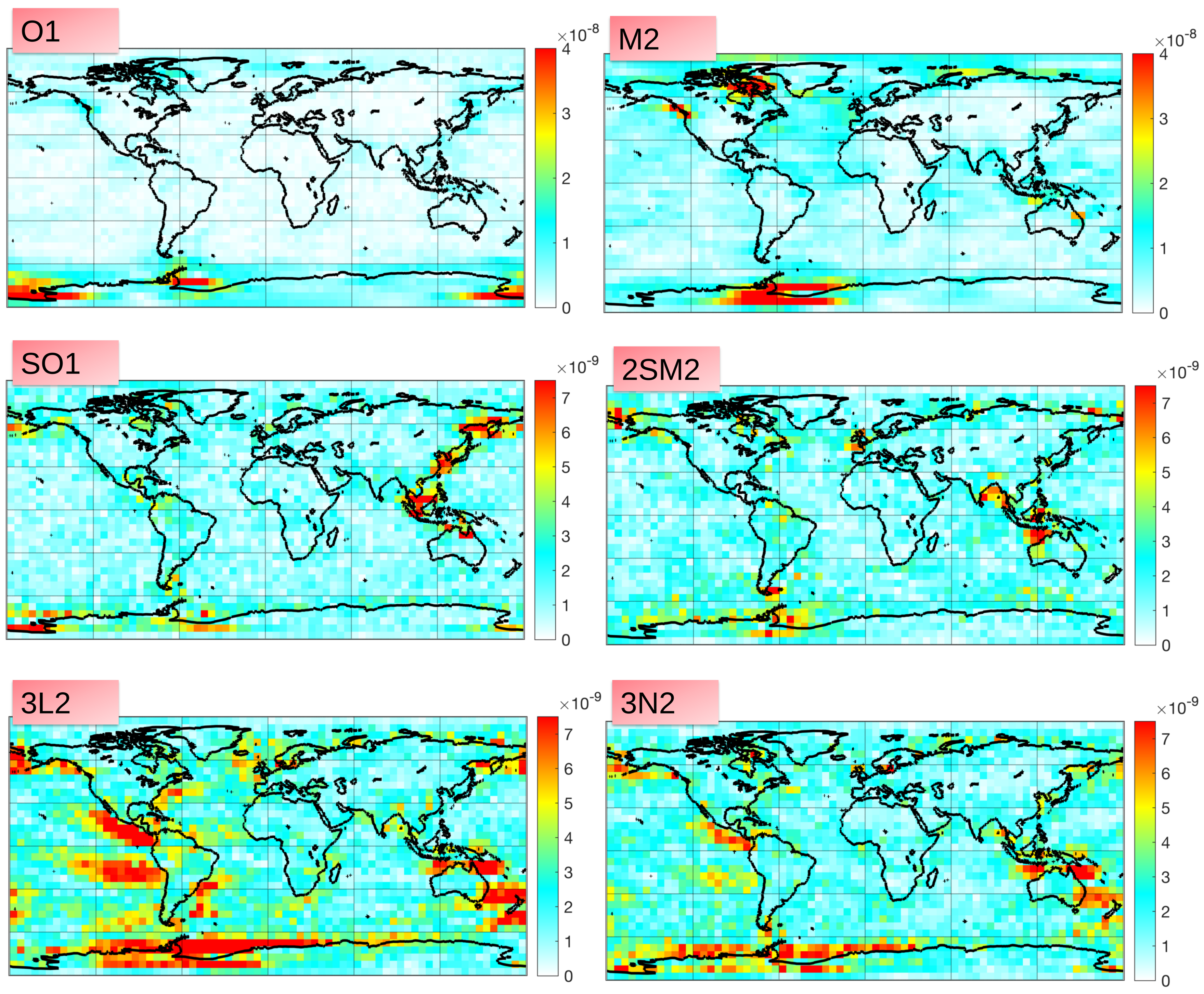
E – Largest tidal constituents

	tide	period [d]	max. ampl. [m/s²/sqrt(Hz)]
1.	O1, MK1	1.0758	7.95E-8
2.	M2, KO2	0.5175	7.78E-8
3.	K1	0.9973	6.08E-8
4.	J1, MQ1	0.9624	2.61E-8
5.	OO1	0.9294	2.43E-8
6.	M(KS2), MSP2, MB2, MA2*	0.5168	2.20E-8
7.	SO1	0.9342	2.11E-8
8.	tau1, MP1	1.0695	1.89E-8

	tide	period [d]	max. ampl. [m/s²/sqrt(Hz)]
9.	mu2, 2MS2	0.5363	1.86E-8
10.	3L2	0.5079	1.68E-8
11.	P1, SK1	1.0027	1.65E-8
12.	N2, KQ2	0.5274	1.58E-8
13.	M3		1.56E-8
14.	SP3, T3		1.47E-8
15.	3N2	0.5275	1.45E-8
…	…		

The tables show the 15 most prominent peaks at tidal periods in the diurnal and semi-diurnal bands. These results are *preliminary*. Please note that on a 5x5 degree grid, only diurnals and semi-diurnals are resolvable (→ D, upper figure). Amplitudes of the ter-diurnal consituents were observed at periods of spectral replicas in the diurnal band.

F – Maps of exemplary constituents



Units of the colorbar: m/s²/sqrt(Hz). Please note the different colorbar limits. Degree-3 tides (3L2, 3N2) describing the asymmetrical part of the lunisolar tide generating potential have just recently been observed globally **[4].** The signatures in the degree-3 tides as observed by the K-band ranging system agree well with altimetry data **[4]** and the hydrodynamic and data unconstrained TiME solutions **[5]**.

G – Conclusions

A detailed analysis of K-band post-fit residuals can be useful for:

- Assessing the quality of background models including (ocean) tide models
- Assessing sub-monthly hydrology not captured by monthly solutions
- Evaluating admittance theory for ocean tide modeling
- Understanding aliasing in GRACE and GRACE-FO products
- Optimizing gravity field recovery processing strategies including parametrization and stochastic modeling

References

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