Temporal gravity field solutions at the AIUB

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Introduction

The processing of CHAMP and GRACE tracking data at the AIUB resulted in the generation of static gravity field models such as AIUB-CHAMP03S (Prange, 2010) and AIUB-GRACE03S, as well as a recently published time series of monthly snapshot solutions from GRACE that allow research on temporal gravity field variations.

The detection of gravity field changes with CHAMP hl-SST data is a challenging task. The long time series of 8 years of CHAMP GPS data processed at the AIUB allows us, however, to combine and solve the normal equations belonging to monthly solutions of different years, significantly reducing the noise level. The resulting spherical harmonic coefficients of the mean monthly solutions contain information about gravity field changes repeating every year. The detected seasonal variations are statistically tested for significance and insignificant variations are surpressed to further reduce the noise level.

The GRACE K-band observable is by far more sensitive to time variable gravity signal, but even there sophisticated filtering techniques have to be applied to isolate the real signal. The large scale seasonal variations obtained from CHAMP and GRACE show good agreement. From GRACE data one can, moreover, estimate secular variations due to ice mass loss and global isostatic adjustment (GIA).

Time variable gravity from CHAMP

The CHAMP satellite was not designed for detecting temporal gravity field changes. In the recent years, however, some progress was made in gravity field determination using observations from spaceborne GPS receivers (e.g., use of empirically estimated antenna PCV models, elevation-dependent weighting, use of the full data sampling rate). At AIUB these improvements contributed to the static gravity field model AIUB-CHAMP03S, which is based on 8 years of CHAMP GPS data. The comparison of monthly CHAMP solutions (contributing to AIUB-CHAMP03S) with monthly GRACE K-band solutions (contributing to AIUB-GRACE03S) shows, however, that the CHAMP solutions are still clearly inferior (see Fig. 1).

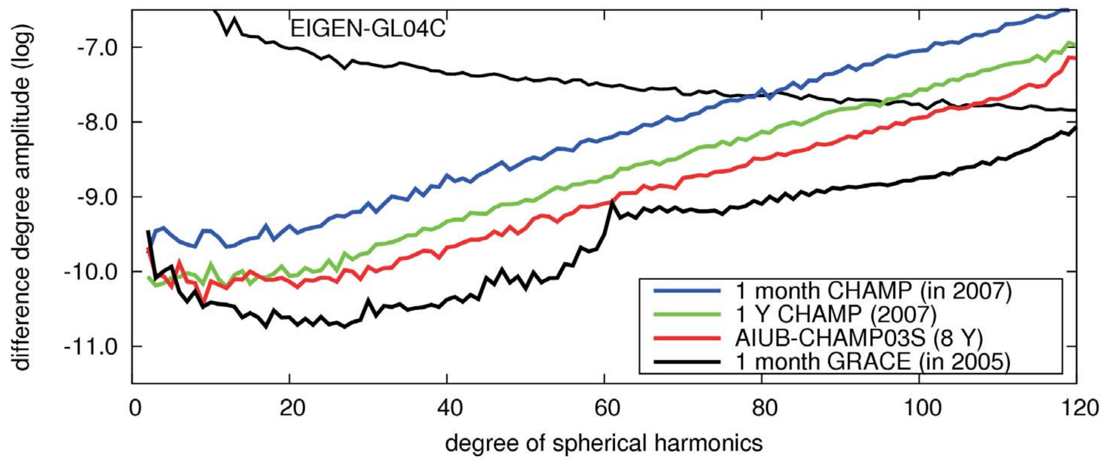

Fig. 1: *Comparison of gravity field solutions generated at AIUB from CHAMP (GPS) and GRACE (GPS and K-band) data: One of the best monthly CHAMP solutions (October 2007), one of the best annual CHAMP solutions (2007), AIUB-CHAMP03S (based on 8 years of CHAMP GPS data), a monthly AIUB-GRACE solution (February 2005).*

The attempt was made to extract temporal gravity field information from CHAMP GPS data of the years 2002-2009: In a first stage monthly gravity field solutions were estimated up to degree and order 10. The coefficients of AIUB-CHAMP03S (degrees 11-120) were introduced as known. The monthly solutions were combined on normal equation level to 8 annual solutions. The derived geoid height differences (annual solution minus monthly solution) indicate some sensitivity for the largest seasonal gravity variations (e.g., in the Amazon river basin), but are generally dominated by noise (see Fig. 2 Top).

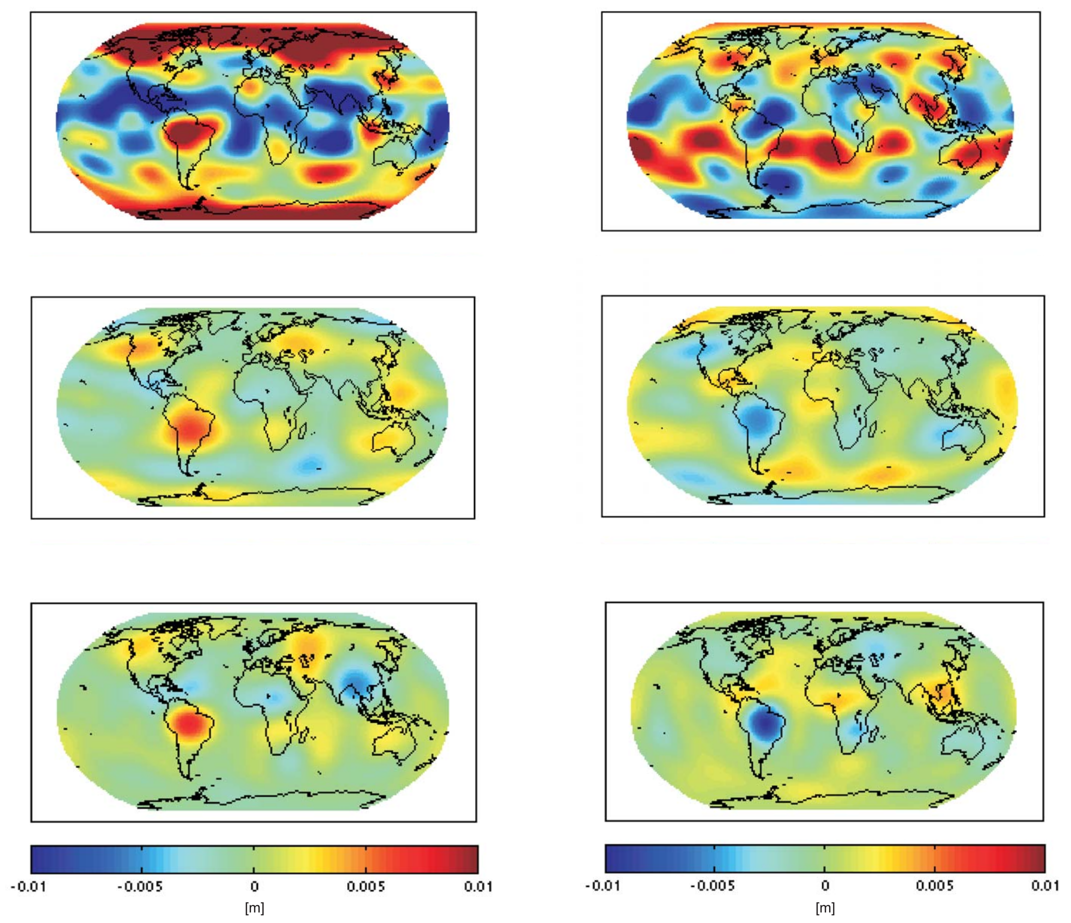

Fig. 2: *Geoid height differences between monthly and mean gravity filed solutions (nmax=10; unit: meter) .* ***Top:*** *Monthly CHAMP solutions from May/November 2007.* ***Middle:*** *Monthly CHAMP solutions for May/November after stacking, model fit, and significance test.* ***Bottom:*** *Monthly GRACE solutions from May/November 2007 for comparison.*

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The monthly CHAMP solutions belonging to the same months of different years were combined on normal equation level. The 12 resulting stacked (or mean) monthly solutions are more homogeneous in quality and have a generally reduced error level (they are in fact 8-month solutions). The time series of each SH coefficient was fitted by a mathematical model consisting of 6 parameters (offset, drift, coefficients of annual and semi-annual periodical functions) and checked for significance using a statistical test as suggested by Davis et al. (2008). The periodical model functions of the SH coefficients that passed the significance test were used to compute fictive SH coefficients for each month. The derived geoid height variations show a significantly reduced noise level. The time variable signal itself is slightly weakened by the filtering (see Fig. 2 Middle). The comparison with geoid height variations computed from monthly GRACE solutions of the same resolution (see Fig. 2 Bottom) shows, however, a good agreement in some regions. A complete 12 month time series of filtered CHAMP geoid height variations is shown in Fig. 3 and may be compared with the GRACE time series shown in Fig. 5.

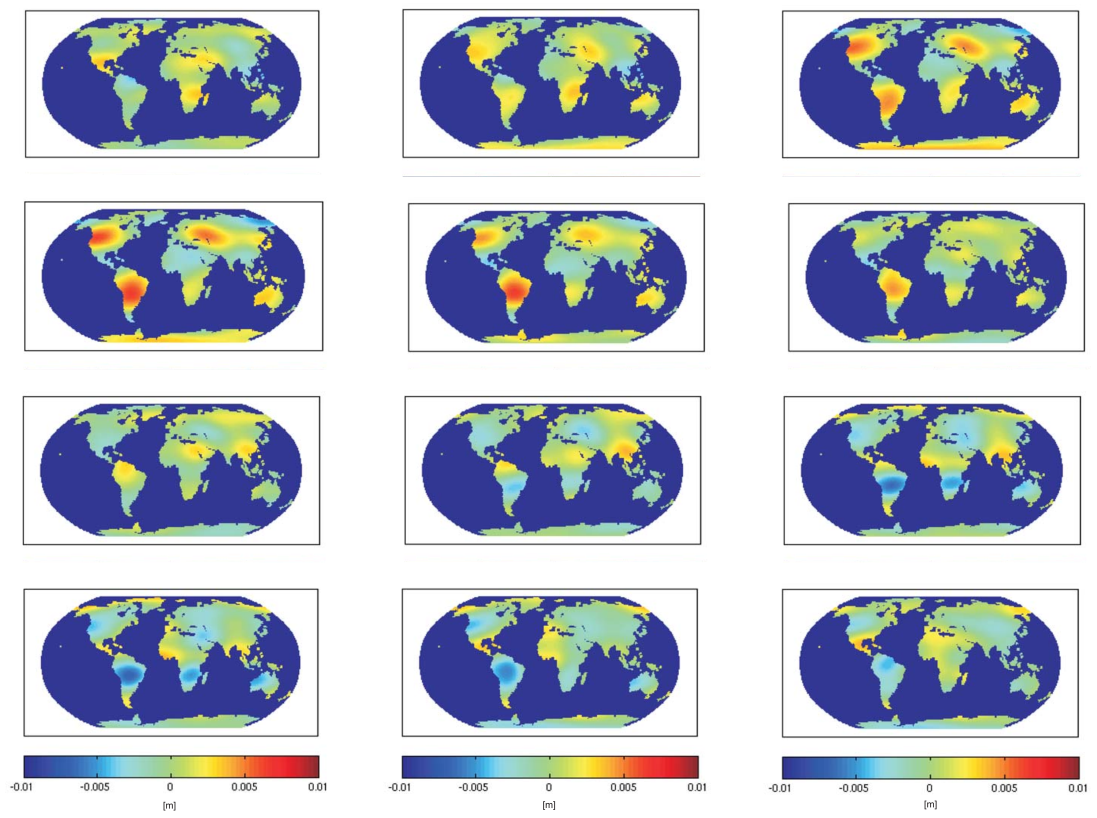

Fig. 3: *Seasonal geoid height variations (nmax=10; unit: meter; temporal resolution: one month), derived from stacked and filtered monthly CHAMP solutions (see also Fig. 2, middle).*

It was checked, whether information about variations of the Earth's gravity field may also be extracted from the unstacked monthly CHAMP gravity field solutions (see geoid height variations in Fig. 2 Top): The water height time series (2003-2008) derived from the monthly CHAMP solutions was compared to corresponding water heights derived from monthly GRACE solutions for selected regions (see Fig. 4 Left). Although the CHAMP results are more noisy there is a good agreement for some regions - at least for the Amazon river basin and for Southeast Asia. The agreement becomes more prominent if the time series are fitted by a mathematical model (trend, amplitudes of periodical functions with annual period; see Fig. 4 Right).

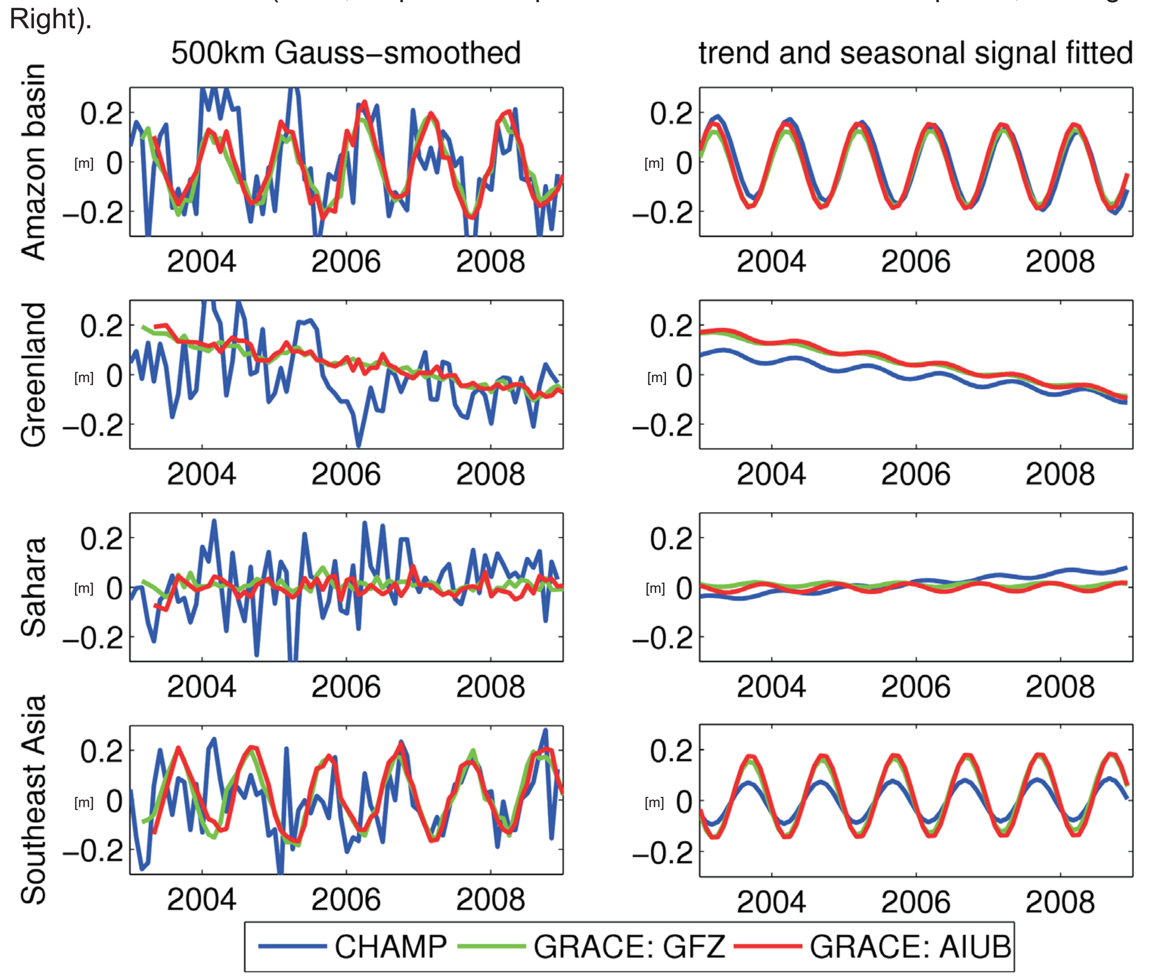

Fig. 4: *Point wise comparison of water height variations (unit: meter) in selected regions for CHAMP and GRACE.* ***Left:*** *Water height variation time series.* ***Right:*** *Model fit of this time series (trend and annual period).*

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Davis, J. L., Tamisiea, M. E., Elósegui, P., Mitrovica, J. X., and Hill, E. M., 2008. A statistical filtering approach for Gravity Recovery and Climate Experiment (GRACE) gravity data. J Geophys Res (Solid Earth), 113(B12):4410+, doi:10.1029/2007JB005043.
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Wahr, J., Molenaar, M., and Bryan, F., 1998. Time variability of the Earth's gravity field: Hydrological and oceanic effects and their possible detection using GRACE. J Geophys Res, 103:3020530230, doi:10.1029/98JB02844.

Time variable gravity from GRACE

Based on the 6 year static gravity field AIUB-GRACE03S (resonance periods excluded) monthly snapshot solutions were estimated up to a max. degree and order of 60. Coefficient wise significance tests of annual, biannual, and secular variations estimated a posteriori from the snapshot solutions reveal sensitivity to seasonal and secular signal at least up to degree 60, while orders beyond 45 contain mainly noise. Nevertheless, smoothing of the monthly fields becomes necessary, whenever the coefficients are transformed to water heights, which roughens the spectrum.
Monthly solutions **AIUB_YYMM_6045**, which were solved up to degree 60 and order 45, are available at ICGEM (http://icgem.gfz-potsdam.de). Coefficients beyond order 45 were filled by the background model AIUB-GRACE03S for convenience of use.

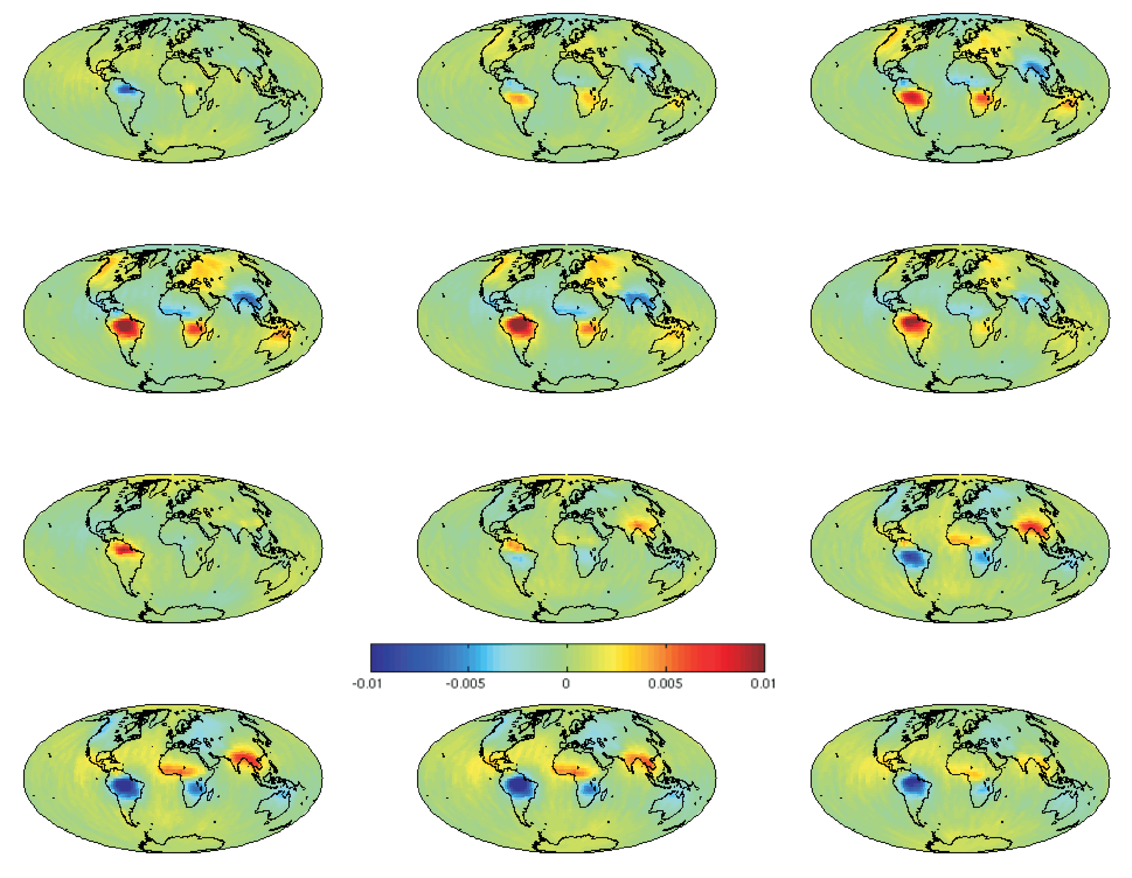


Fig. 5: *Annual and biannual geoid variations [m], estimated coefficient wise from a time series of monthly snapshot solutions up to degree 45. Only significant terms are taken into account to synthesize geoid variations. No smoothing has been applied.*

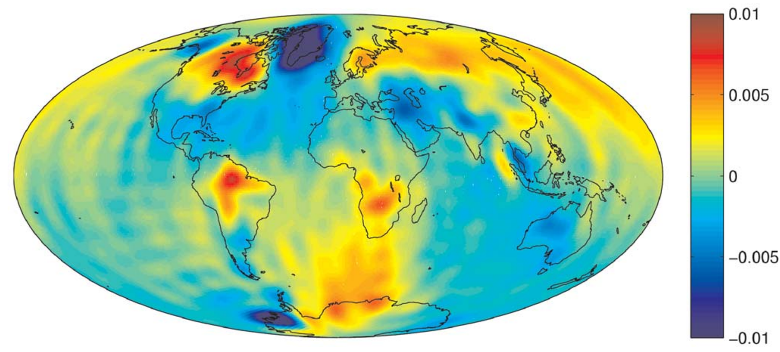
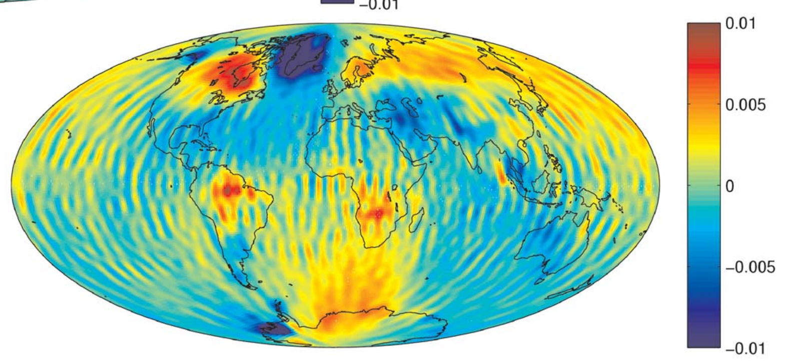


Fig. 6: *Trends, estimated coefficient wise from a time series of monthly snapshot solutions up to degree 30, do not need further smoothing, if only significant terms are taken into account to synthesize geoid variations.*

Fig. 7: *Trends, estimated coefficient wise from a time series of monthly snapshot solutions up to degree 60, show striping artefacts, even if insignificant terms are omitted. Smoothing would inevitably destroy many meaningful details.*



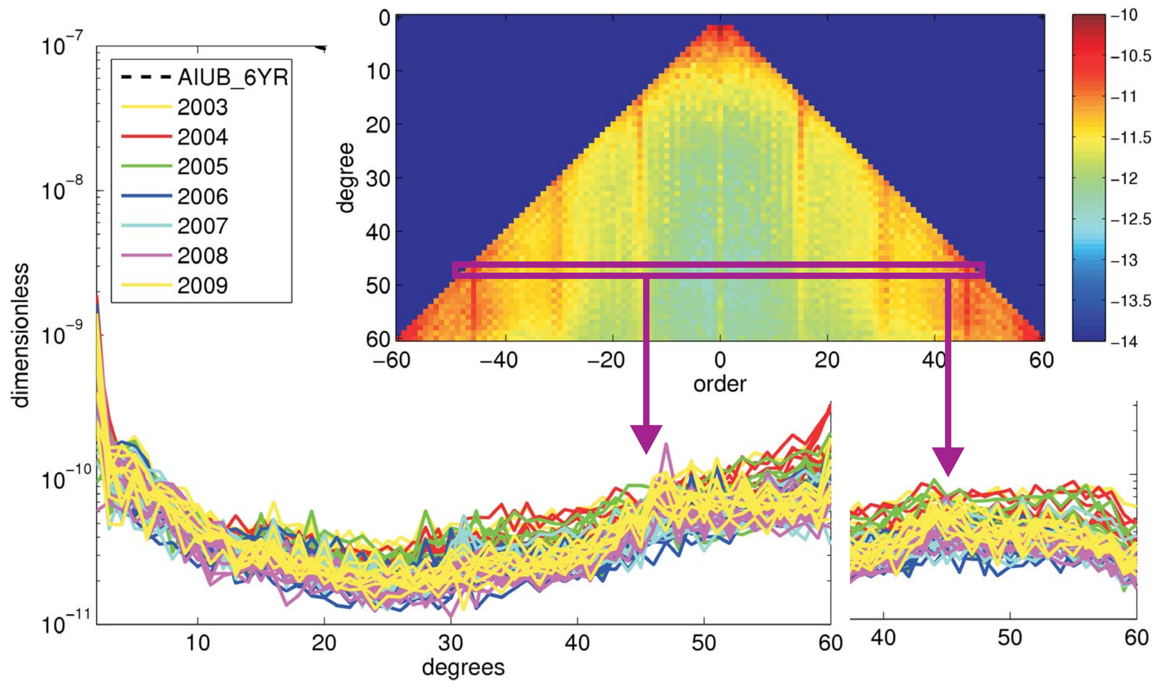


Fig. 8: *The triangle plot of calibrated errors (top right) shows a significant degradation of the quality of monthly gravity field coefficients from the resonant order 46 on, which is also visible in the difference degree amplitudes between the static and monthly solutions (bottom left). When coefficients are summed up to order 45 only (bottom right), the continuously high quality of coefficients beyond degree 45 becomes visible.*

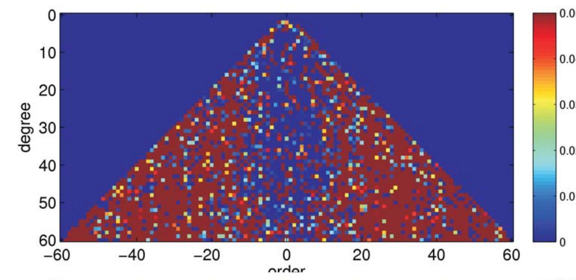


Fig. 9: *In a simple model trend, annual, and biannual variations per coefficient were estimated a posteriori from monthly snapshot gravity field solutions up to degree 60. These were statistically tested for significance. To the left the significance of the trend parameters is shown in a triangle plot. Blue means significant, red insignificant.*

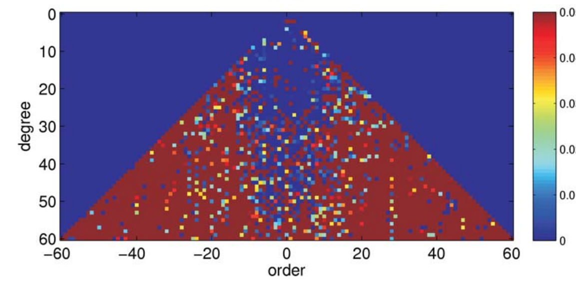


Fig. 10: *Significance of annual gravity variations per coefficient (blue=significant, red=insignificant). For the low orders significant annual variations can be expected nearly up to degree 60, while the higher orders seem to contain mainly noise.*

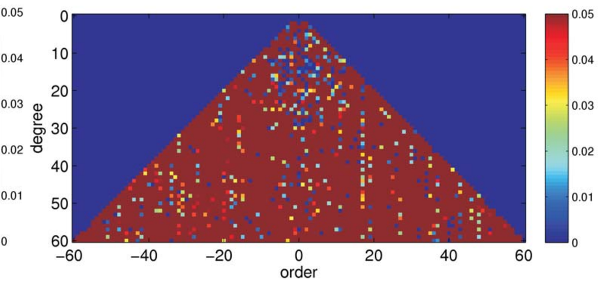


Fig. 11: *Significance of biannual gravity variations per coefficient (blue=significant, red=insignificant). Only the lowest degrees and orders show some sensitivity.*

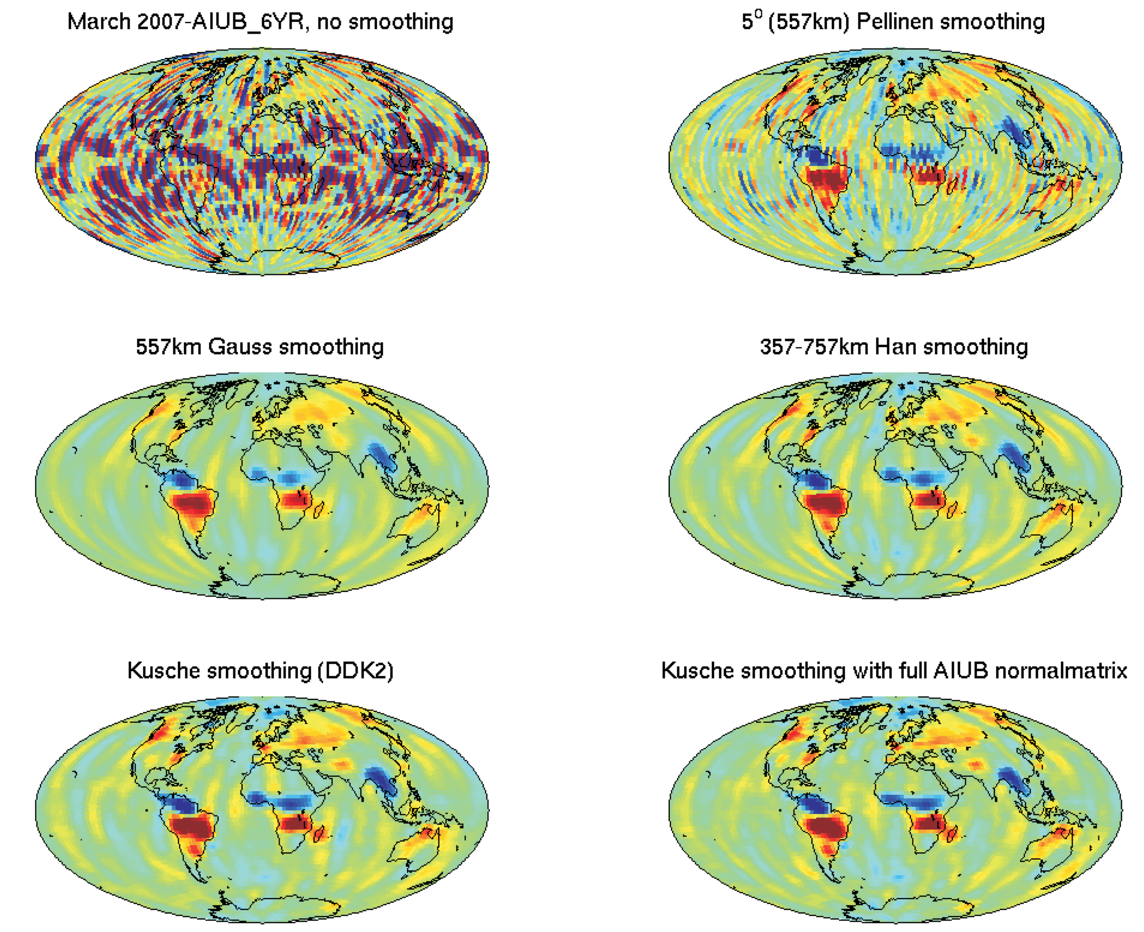


Fig. 12: *When the coefficients of temporal gravity variations are transformed to variations in water height, high degrees get higher weights, which results in a roughening of the fields. Above the effects of different smoothing algorithms on an example month (March 2007, max. degree=60) are shown. The color scale shows variations from -20 cm (blue) to +20 cm (red). Due to its easy implementation the Gauss smoothing (Wahr et al., 1998) is still very common. The Kusche smoothing (Kusche et al., 2009) is a regularization towards modeled signal and results in somewhat higher amplitudes over the continents.*

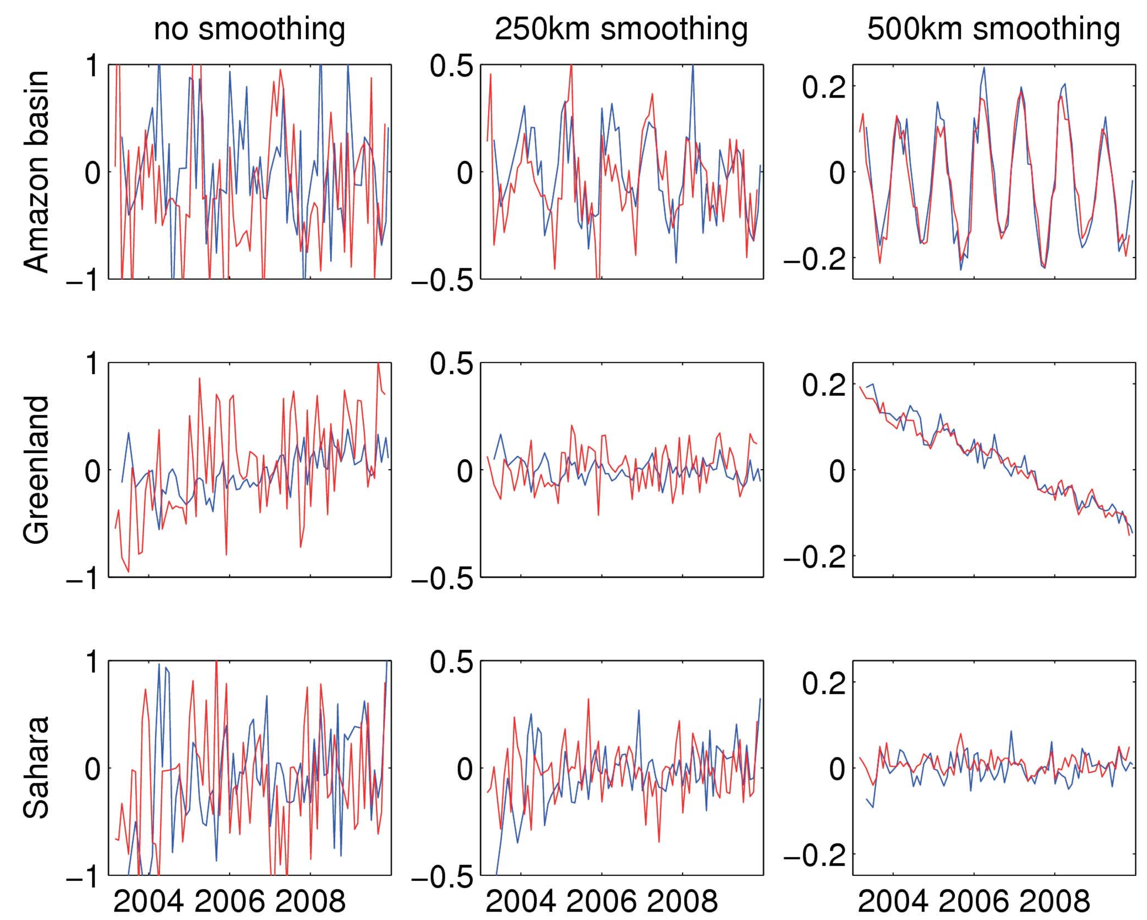


Fig. 13: *A point wise evaluation of variations in water height [m] in three exemplary regions once more shows the importance of proper smoothing. In the Amazon basin a seasonal variation due to the hydrological cycle is expected, in Greenland ice mass loss is predominant (superimposed by seasonal snowfall), while the signal in the Sahara may be attributed mainly to noise (red=GFZ, blue=AIUB).*