Receiver Clock Modelling for GPS-only Gravity Field Recovery from GRACE

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Introduction & motivation

Previous results from the authors (Orliac et al., 2011, Weinbach and Schön, 2011) show that for stations connected to highly stable clocks (H-Maser), kinematic Precise Point Positioning (PPP) solutions for the height component can be improved up to 70% if the receiver clock is modelled with a second order polynomial instead of estimating independent epoch-wise clock corrections. Although those initial results are very promising, the applicability of such an approach is rather limited since very stable clocks are hardly portable.

The only truly kinematic objects carrying a GPS receiver connected to a very stable clock are the twin GRACE satellites. In this study we investigate the impact of the deterministic modelling of the receiver clocks in the determination of kinematic PPP orbits for the two GRACE satellites. Two independent solutions from two institutions, namely the Astronomical Institute of the University of Bern (**AIUB**) and the Institut für Erdmessung (**IfE**) of the Leibniz University of Hannover, using independent software and strategies, were computed and compared.

The kinematic orbits obtained with modelled clocks are compared to standard kinematic and reduced-dynamic solutions where receiver clock corections are estimated independently every epoch. Finally, based on one month of data, gravity fields from all kinematic solutions are derived and compared.

Data Processing

IfE Solution

The kinematic orbit determination of the GRACE satellites at the IfE is based on the PPP approach using final ephemeris and satellite clock corrections from CODE (Center for Orbit Determination in Europe). Ionosphere-free pseudorange and phase observations at 30 s intervals are processed assuming elevation-independent standard deviations of 60 cm and 2 mm, respectively. Observations at elevation angles below 5° are rejected. Empirical phase center variations (PCV) were used in the processing according to Jäggi et al. (2009b).

The receiver clock offset is either estimated epoch-wise (**E-W**) independently or modelled by a sequence of piece-wise linear parameters (**Mod**). Based on an empirical analysis of the kinematic position residuals with respect to a reduced-dynamic orbit, a parameter spacing of 60 s with relative constraints of 0.8 ns/h was chosen.

AIUB Solution

The GRACE orbit determination performed at AIUB relies as well on CODE final products. As opposed to the IfE approach, only carrier phase data (ionosphere-free linear combination) is used in essence. Observations below 5 degrees are ignored. The same PCV as IfE were used. The processing was performed using the Bernese GNSS Software (BSW, Dach et al., 2007).

The clock modelling is performed at the normal equation (NEQ) level. Clocks were modelled as unconstrained piece-wise linear function over 24 hours with 5 minutes knot spacing. In a first PPP step, NEQs are produced with epoch-wise receiver clocks set up, but not solved for. NEQs are only solved after the parameter transformation. From the estimated clock model parameters, a new clock RINEX file is generated and introduced as known information in a second PPP step.

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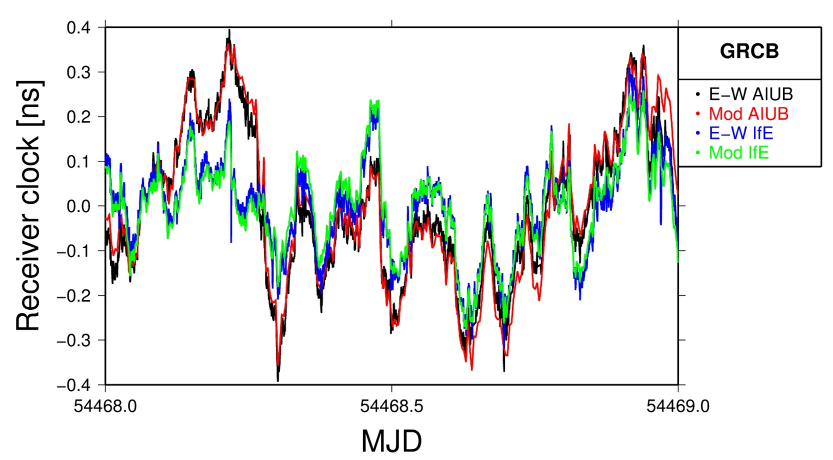

Figure 1: Clock time series for GRACE-B on DOY 003 of 2008.

Kinematic orbits: impact of clock modelling

The modified Allan devation (MDev) together with the power spectral density (PSD) for epoch-wise and modelled clock time series are presented for GRACE-B in Fig. 2 for a typical day (03.01.2008) of the processed period (Jan. 2008). For both the AIUB and IfE solutions the impact of clock modelling is clearly visible and shows the expected behaviour with a decrease of the MDev for averaging intervals of length varying between the data sampling rate (30 s) and the vicinity of the knot spacing of the piece-wise linear model. Fig.1 presents the corresponding time series for all four solutions.

The PSD estimates for both E-W time series show power exceeding the background noise at around 3.3 mHz (5 min), frequency at which original GPS satellite clocks are estimated, before being augmented (see Bock et al., 2009). The clock modelling in the AIUB solution fully removes the power found in the E-W time series for periods centered on 300 s, what is less true for the IfE solution, for which a lobe at ~13 mHz is introduced (see the right plot on Fig. 2).

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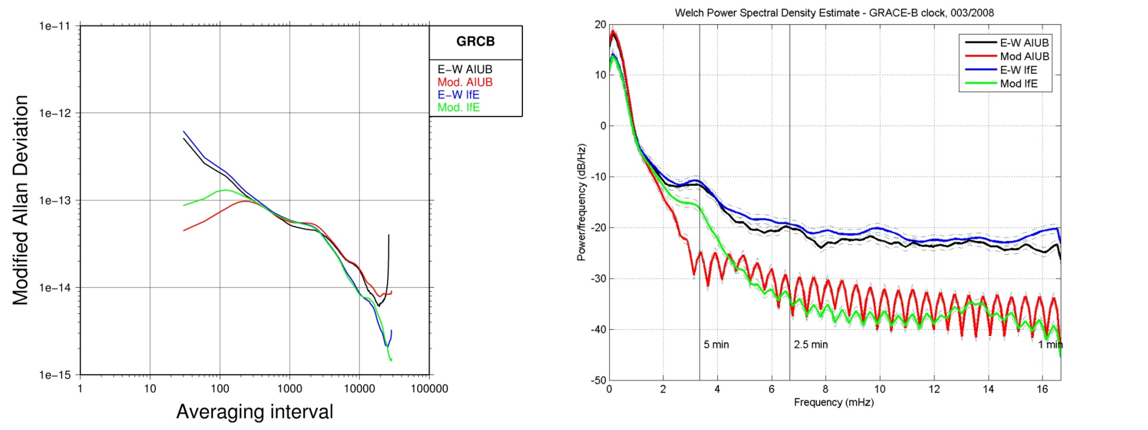

Figure 2: Modified Allan deviation (left) and power spectral density estimates (right) for AIUB and IfE epoch-wise and modelled clock time series for DOY 003 of 2008.

In Fig. 3, the corresponding PSD estimates for the radial, along-track, and cross-track orbit residuals are presented with respect to a reduced-dynamic solution from AIUB. For the AIUB solution, only the radial component is affected by clock modelling, with power introduced at ~3.3 mHz. The major difference between the AIUB and IfE solutions is the power present in the cross-track component the IfE solution for highest frequencies (~16 mHz), which cannot be attributed to clock modelling, because it is present in the E-W solution as well.

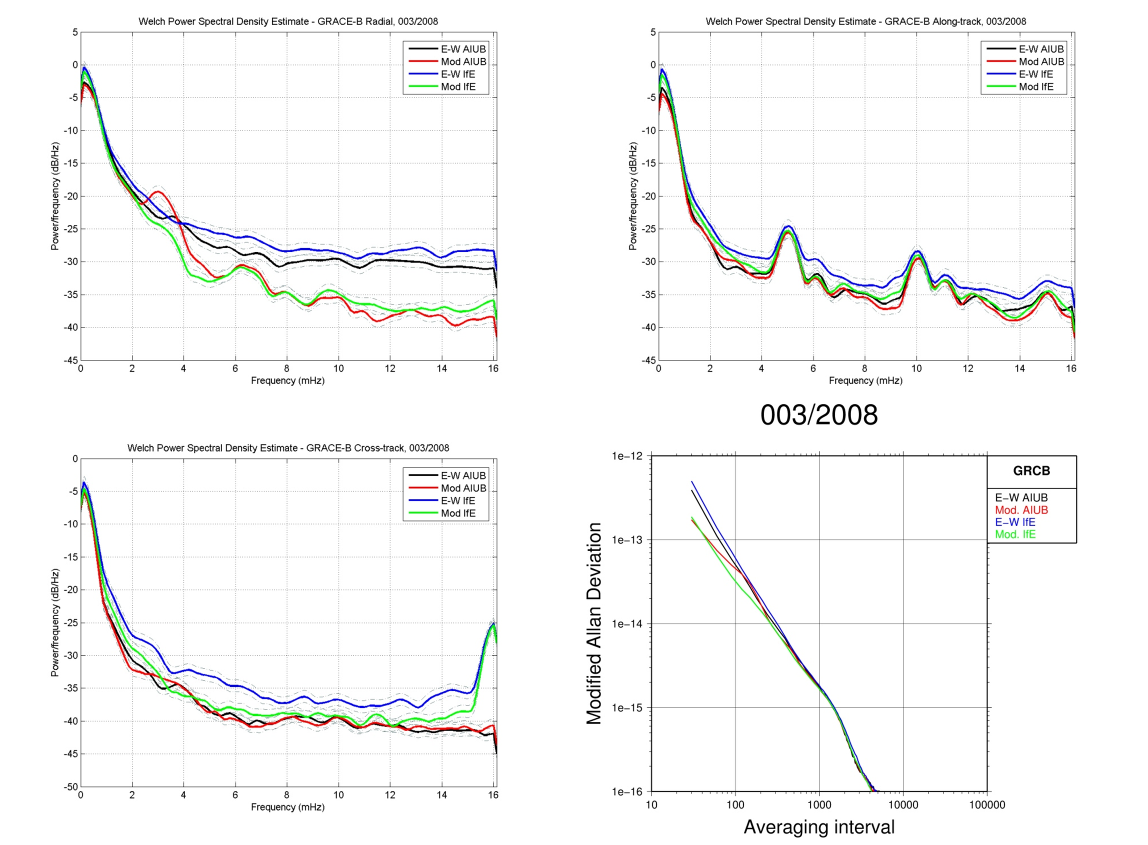

Figure 3: Power spectral density estimates for GRACE-B positions residuals on DOY 003 of 2008 for the radial (top left), along-track (top right), and cross-track components (bottom left). Modified Allan deviation for the epoch to epoch differences of residuals in the radial component (bottom right).

The daily RMS time series for all four kinematic solutions w.r.t the K-band ranges (KBR) are presented in Fig. 4. For reference, the reduced-dynamic solution was added. Overall, the AIUB solutions perform better, with very similar behaviour for both E-W and modelled clocks, which is expected, since it was shown that the clock modelling for AIUB was affecting the radial component only (see Fig. 2). For the IfE solution, the modelling of the receiver clock has overall a beneficial impact, reducing the average RMS by several mm. Higher values for the RMS of KBR residuals may be due to short bad periods in daily time series (see e.g. DOY 013 of 2008 on the right plot of Fig. 4).

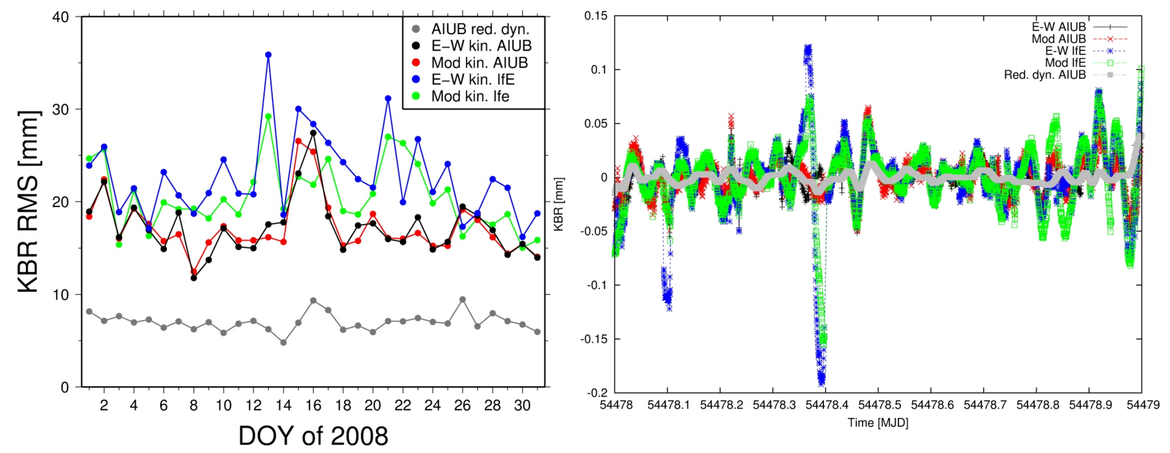

Figure 4: K-Band range daily RMS time series over January 2008 (left) and KBR time series for DOY 013 of 2008 (MJD 54478, right).

Tab. 1 presents the mean daily RMS (over Jan. 2008) of the residuals between the kinematic solutions and a reduced-dynamic solution from AIUB which is taken as a reference. The top part of Tab. 1 shows that for both AIUB and IfE, the kinematic solutions slightly improved on each component by respectively 1 and 2 mm when clocks are modelled.

The bottom part of Tab. 1 shows similar numbers for the epoch to epoch differences. They basically reflect the noise of the solutions on the highest frequencies (the low period signals being removed, see Fig. 3 (bottom right)). To expect improvements in the gravity field recovery, a significant reduction of the RMS shall be observed from the E-W to the Mod solution, which is the case, with a reduction of the mean RMS of 20% for AIUB and 46% for IfE in the radial component (to reach comparable value of 4.5 and 4.0 mm).

	Radial		Along-track		Cross-track	
	mean	st.dev.	mean	st.dev.	mean	st.dev.
E-W AIUB	1.98	0.23	1.67	0.25	1.31	0.20
Mod AIUB	1.88	0.21	1.56	0.20	1.25	0.20
E-W IfE	2.50	0.32	2.03	0.34	1.70	0.43
Mod IfE	2.30	0.24	1.83	0.27	1.50	0.29
E-W AIUB	0.56	0.05	0.36	0.02	0.18	0.02
Mod AIUB	0.45	0.05	0.35	0.02	0.18	0.02
E-W IfE	0.74	0.05	0.43	0.04	0.33	0.02
Mod IfE	0.40	0.05	0.38	0.02	0.30	0.01

Table 1: Mean daily RMS in cm (and associated standard deviation) of GRACE-B radial, along-track, and cross-track kinematic positions residuals with respect to the reduced-dynamic solution. Top: residuals; Bottom: epoch to epoch differences of residuals.

Gravity field recovery

The CMA (Celestial Mechanics Approach, Jäggi et al., 2009a) was used to compute gravity field solutions up to a maximum degree of 90 based on different sets of one month of GRACE-B kinematic positions (see Figs. 5 and 6). Provided that covariance information of kinematic positions is not taken into account for gravity field recovery, Fig. 5 confirms a clear overall reduction of the degree difference variances when using kinematic positions based on modeled clocks as to be expected from Tab. 1. However, the benefit of using modeled clocks, i.e., using kinematic positions with improved radial accuracy, is completely annihilated when covariance information is taken into account for gravity field recovery (see Fig. 5).

Moreover, spurious signals of not yet resolved origin (see Fig. 2 (right)) may no longer be absorbed by the epoch-wise clock estimates and appear in the kinematic positions and are eventually seen as artifacts in the recovered gravity field solutions. Fig. 5 shows that artifacts also occur for a different time period of one month in 2009, but with different characteristics. The artifacts are present in the solutions from both AIUB and IfE. No improvement of gravity field recovery from kinematic positions could thus be achieved so far by clock modeling.

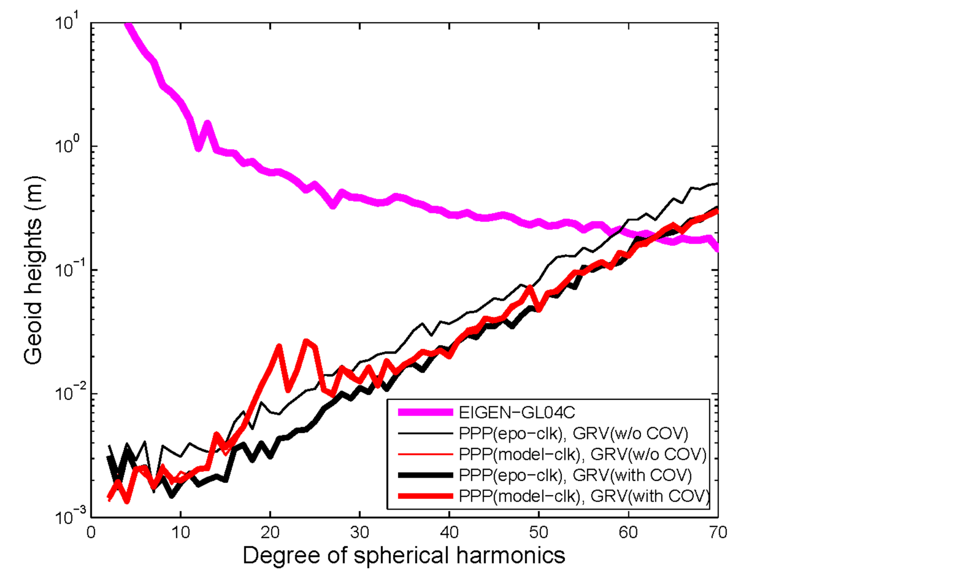

Figure 5: Square-roots of degree difference variances of monthly gravity field recoveries from one month of GRACE B kinematic positions in 2009. Clock modeling strategies for PPP and covariance handling for gravity field determination are compared.

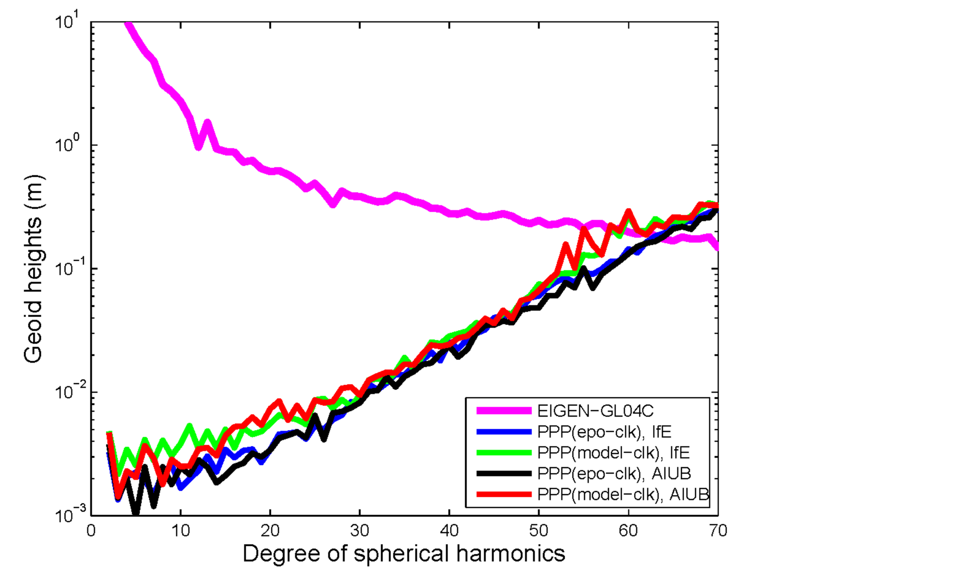

Figure 6: Square-roots of degree difference variances of monthly gravity field recoveries from one month of GRACE B kinematic positions in 2008. Clock modeling strategies for PPP solutions from AIUB and IfE are compared.

Conclusions

Out of the results of this study, the modelling of the GRACE satellite clocks did not yet improve the recovery of gravity field parameters, at least when epoch-wise covariance information is used. By smoothing short term clock variations, it was expected that a stabilization of the kinematic solution would help in the recovery of the spherical harmonic coefficients of higher degrees.

Further investigations are planned, such as taking into account covariance information over longer time spans, and not only the epoch-wise one in the recovery of the gravity field.

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