Trägerphasenbasierte kinematische Orbitbestimmung erdnaher Satelliten

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Motivation

- Low Earth Orbiters (LEO) in up to 1000 km altitude are used for Earth observation
- Absolute timing of all sensor data and precise LEO positions are mandatory
- Errors in Precise Orbit Determination (POD) transfer into other satellite products
- Global gravity field recovery needs high-precision LEO orbits

Characteristics of kinematic orbits

- Kinematic orbits: discrete representation of the satellite's trajectory
- Positions from GNSS observations, orientations from star camera data
- No force models for satellite dynamics, no numerical orbit integration (Švehla and Rothacher, 2005)
- Results are three-dimensional coordinates for every epoch, receiver clock errors and phase ambiguities

Our basic approach for kinematic orbits

- Precise Point Positioning (PPP) as known from terrestrial case using final GPS orbits from the IGS
- Modeling of all GNSS related error sources, like GNSS satellite clock errors, GNSS satellite Phase Center Offsets (PCO) and Variations (PCV), relativistic effects, Phase Wind-Up (PWU) (Beyerle, 2009)
- Eliminating 1^{st} order ionospheric delay with ionospheric-free linear combination for code and phase observations
- Elevation cut-off angle 5°, C/N_0-depending observation weighting (Luo et al., 2009)
- Parameter estimation via a batch Least-Squares Adjustment for daily 24 hours observation files
- Two groups of parameters: epoch-wise (coordinates, receiver clock errors) and global (phase ambiguities)
- Adjustment with parameter pre-elimination (Heck, 1975)

IfE advanced kinematic orbit

Receiver Clock Modeling (RCM)

- Approximation of the epoch-wise receiver clock error via piecewise linear polynomials
- Polynomial coefficients are time offsets o_i and frequency offsets δf_i (cf. figure 1)
- Validity of coefficients depends on oscillator frequency stability
- RCM is feasible as long as the Allan deviation $\sigma_y(\tau)$ of the oscillator is smaller than the white noise of the GPS phase clock (cf. figure 2)
- The satellites of the Gravity Recovery And Climate Experiment (GRACE) mission are equipped with Ultra Stable quartz Oscillators (USO)
- USO frequency stability is shown in figure 2 according to Dunn et al. (2002)
- For the GRACE USO each polynomial can have a maximum length of 60 s (Weinbach and Schön, 2013)
- Clock constraints restrict variation of consecutive parameters
- σ_{gap} constraints the offset between the end of polynomial i and the beginning of polynomial $i+1$
- σ_{slope} limits the slope of consecutive polynomials
- Values for the clock constraints should be chosen with care
- The time prediction error RMS_x is given by $RMS_x(\tau) = \tau \cdot \sigma_y(\tau)$
- $\sigma_{gap} = RMS_x(T) \cdot c$ with $T =$ observation epoch spacing
- $\sigma_{slope} = \frac{RMS_x(\tau) \cdot c}{\tau}$ with $\tau =$ maximum length of polynomial
- $\sigma_{gap} = 0.5\ mm$ for GRACE USO
- $\sigma_{slope} = 0.05\ \frac{mm}{s}$ for GRACE USO
- Jumps, huge variations, discontinuities and high-frequency noise can be suppressed with RCM (cf. figure 3)
- With RCM the former epoch-wise clock parameters become global parameters in the adjustment
- Less number of parameters and changed correlation between all estimated parameters through RCM

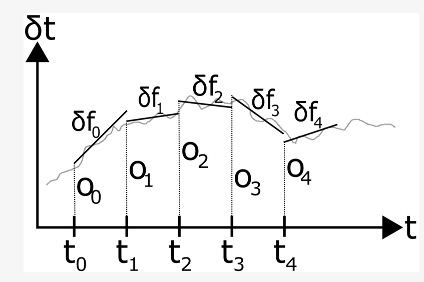

Figure 1: RCM with piecewise linear polynomials

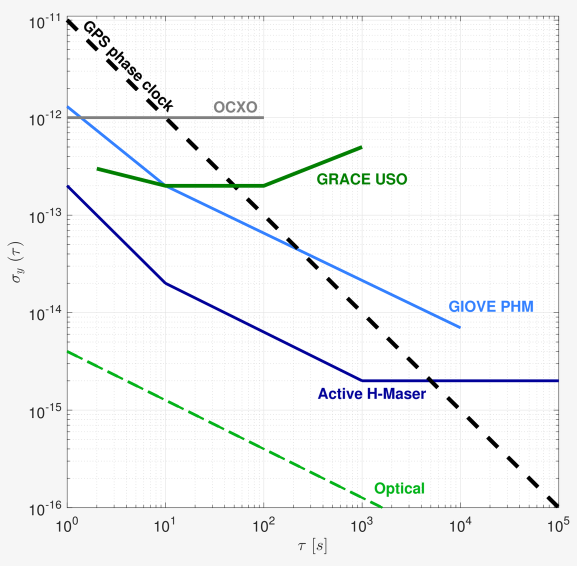

Figure 2: Allan deviation $\sigma_y(\tau)$ of selected high-precision oscillators

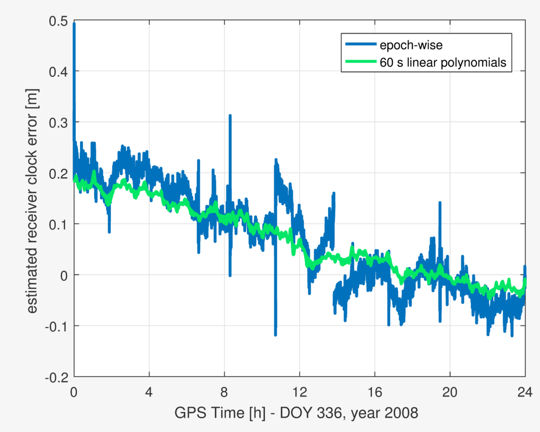

Figure 3: Receiver clock error with and without RCM, GRACE B, 1^{st} Dec 2008

Residual maps

- A-priori Phase Center Variations (PCV) from terrestrial calibrations seem not being able to absorb the total effect occurring in orbit
- Different approaches for in-situ PCV calibration have been made
- Our approach: residual maps (cf. figures 4 to 9)
- Monthly outlier screened and stacked a-posteriori observation residuals are taken as observation corrections in a seconds computation run
- Separated in code and phase observations and separated by LEO spacecraft
- While the phase residual maps for GRACE A and B appear quite similar (cf. figures 7 and 8), the code residual maps show big differences (cf. figures 4 and 5)
- Figure 6 shows the inhomogeneous coverage of the number of observations over the skyplot
- The standard deviations of the stacked phase residuals per bin are shown in figure 9
- Uncalibrated in-situ PCVs, near-field multipath and other systematics are mitigated

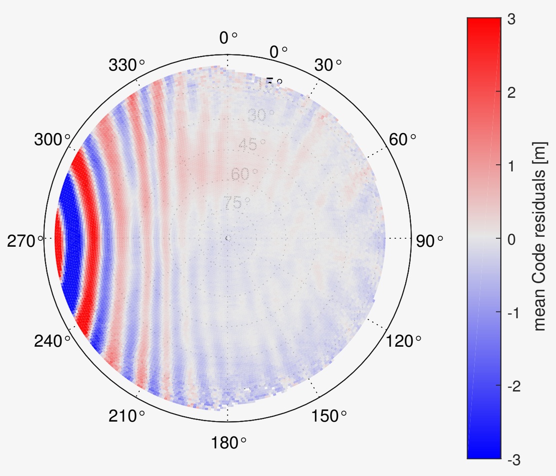

Figure 4: GRACE A: code observation residual map for Dec 2008

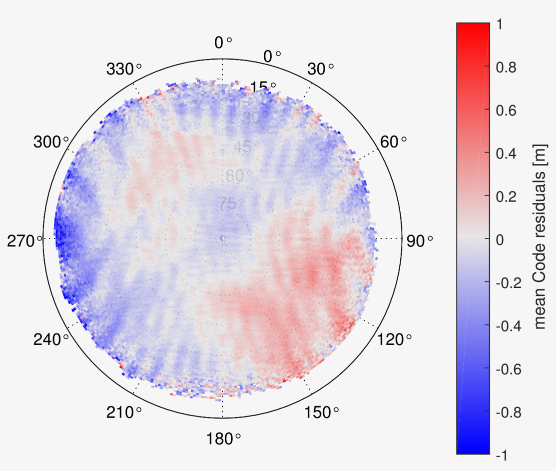

Figure 5: GRACE B: code observation residual map for Dec 2008

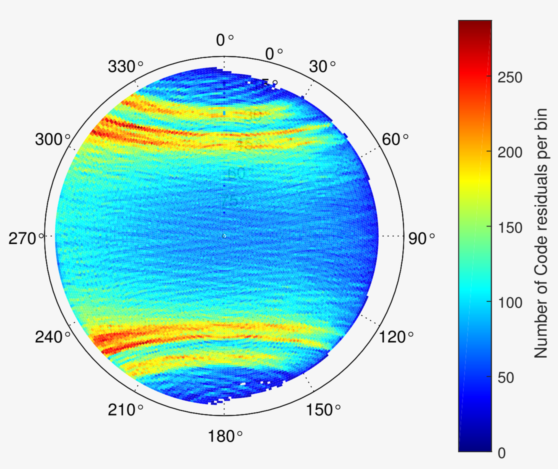

Figure 6: GRACE A: number of code observations per bin for Dec 2008

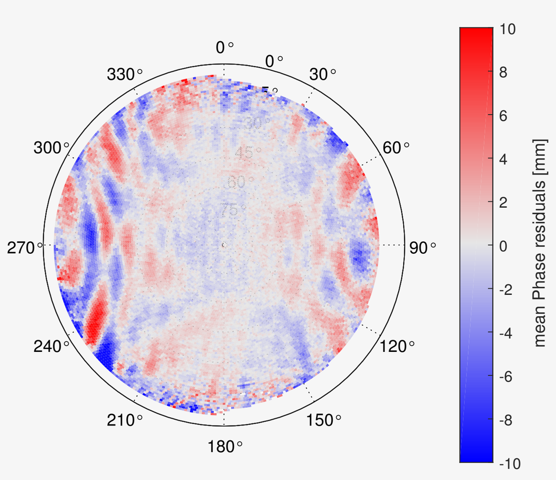

Figure 7: GRACE A: phase observation residual map for Dec 2008

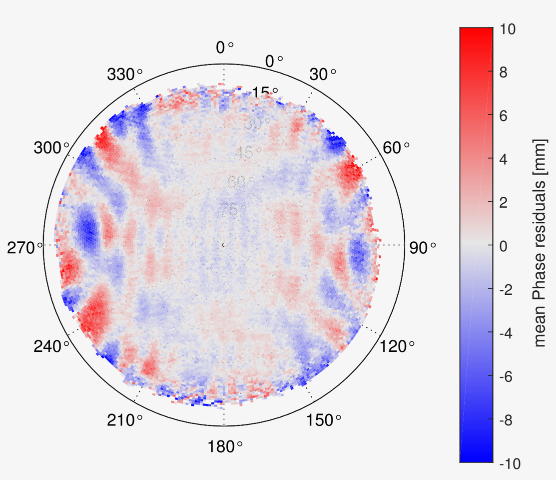

Figure 8: GRACE B: phase observation residual map for Dec 2008

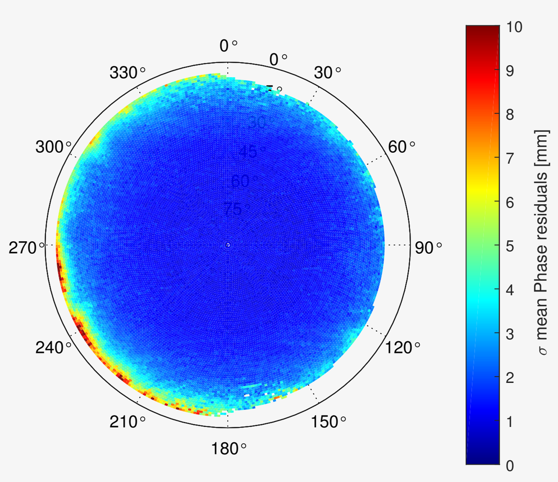

Figure 9: GRACE A: standard deviation of phase residuals per bin for Dec 2008

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IfE phase only kinematic orbit

- GRACE: Switched on GPS occultation antenna causes multipath-like errors in code observations (cf. figure 4)
- Idea: same configuration as IfE advanced kinematic orbit, but no use of less precise code observations
- Through RCM the parameter adjustment with phase observations only is feasible
- First results indicate that the position residuals with phase only are not as precise as the IfE advanced kinematic orbit at the moment (cf. table 1)

Results of IfE kinematic GRACE orbits

- Figures 10 to 13 show the comparison between our kinematic orbit solutions w.r.t. the reduced-dynamic orbit from Jet Propulsion Laboratory (JPL) (Wu et al., 2006) for a typical day

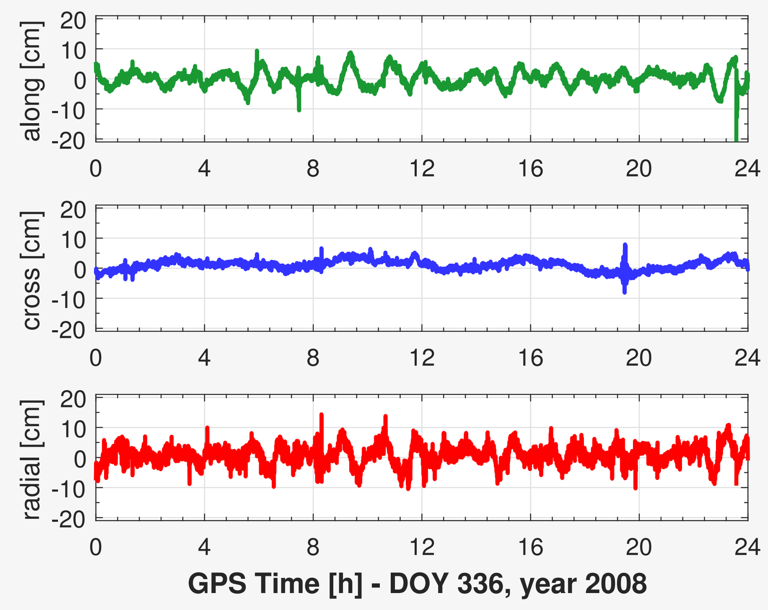

Figure 10: Differences of IfE basic kinematic orbit w.r.t reduced-dynamic orbit from JPL for GRACE A for 1^{st} Dec 2008

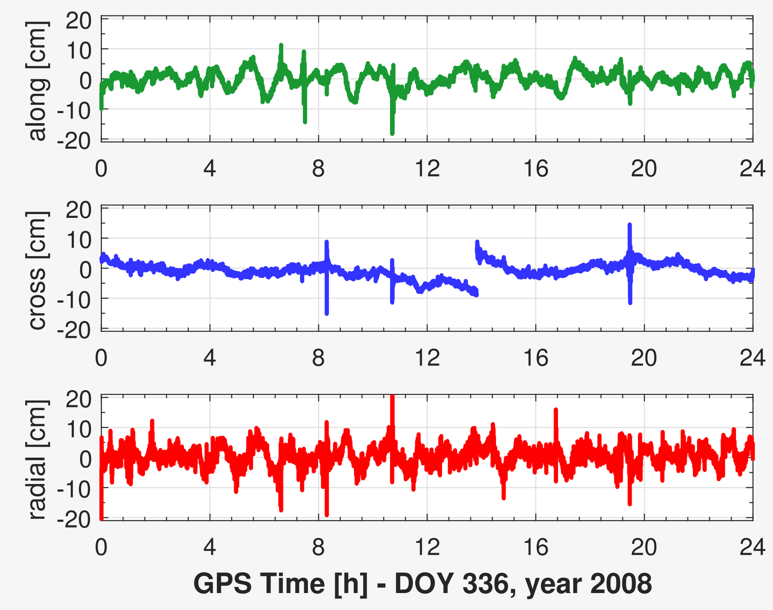

Figure 11: Differences of IfE basic kinematic orbit w.r.t reduced-dynamic orbit from JPL for GRACE B for 1^{st} Dec 2008

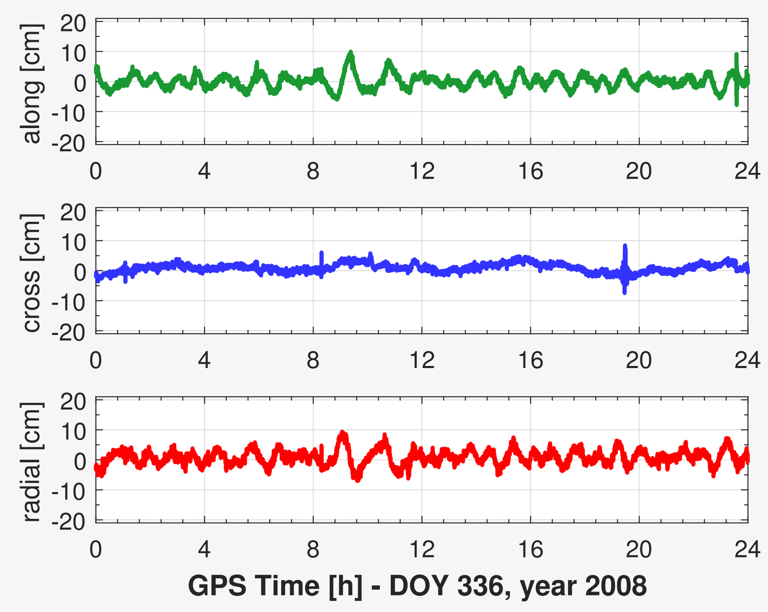

Figure 12: Differences of IfE advanced kinematic orbit w.r.t reduced-dynamic orbit from JPL for GRACE A for 1^{st} Dec 2008

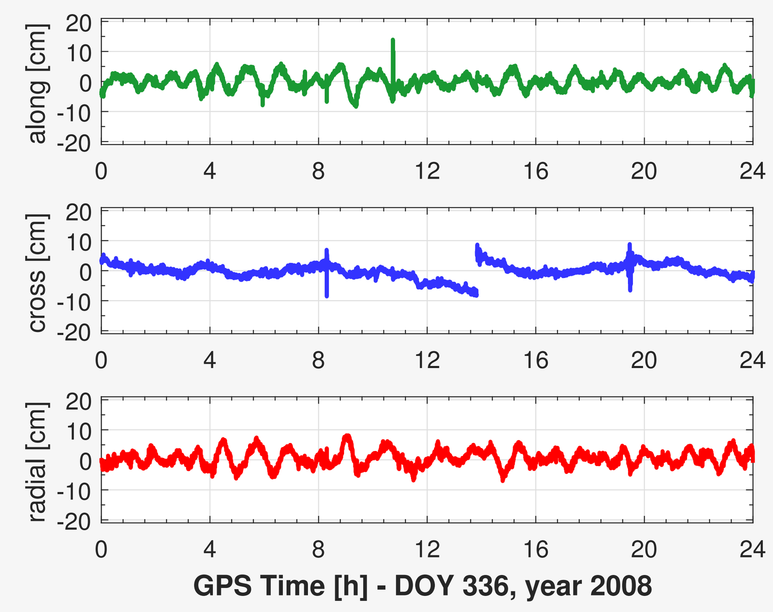

Figure 13: Differences of IfE advanced kinematic orbit w.r.t reduced-dynamic orbit from JPL for GRACE B for 1^{st} Dec 2008

- We compare our orbits and the kinematic orbit from the Institute of Geodesy (IfG) from TU Graz (Zehentner and Mayer-Gürr, 2013) with the reduced-dynamic orbit from JPL (cf. table 1)
- Only days were taken where all approaches have a computed solution (20 out of 31 days)

Table 1: IfE kinematic orbit solutions and IfG kinematic orbit for 20 days of Dec 2008 w.r.t. reduced-dynamic orbit from JPL

[cm]		GRACE A				GRACE B			
		IfE basic	IfE phase only	IfE advanced	IfG	IfE basic	IfE phase only	IfE advanced	IfG
MEAN	along	0.5	0.4	0.1	0.0	-0.2	0.0	0.0	0.0
	cross	1.3	1.3	1.3	-0.2	-0.9	-0.8	-0.4	-0.3
	radial	1.1	1.1	1.2	0.1	0.7	0.7	0.7	0.3
STD	along	4.0	3.1	2.6	2.0	4.4	3.1	2.4	1.5
	cross	4.4	2.7	2.4	1.2	3.1	2.6	2.1	1.2
	radial	4.2	3.9	2.8	1.9	4.2	3.2	2.6	1.5
RMSE	along	4.0	3.2	2.6	2.0	4.4	3.1	2.4	1.5
	cross	4.6	3.0	2.7	1.2	3.2	2.7	2.2	1.3
	radial	4.3	4.1	3.0	1.9	4.2	3.3	2.7	1.6
	3D	7.5	6.0	4.8	3.0	6.9	5.3	4.2	2.5

- GPS observations show a high number of total loss of lock near the magnetic equator for descending orbit arcs starting from 11^{st} of December
- GRACE A is more effected by this, leading to higher 3D-RMSE values (cf. figure 14)

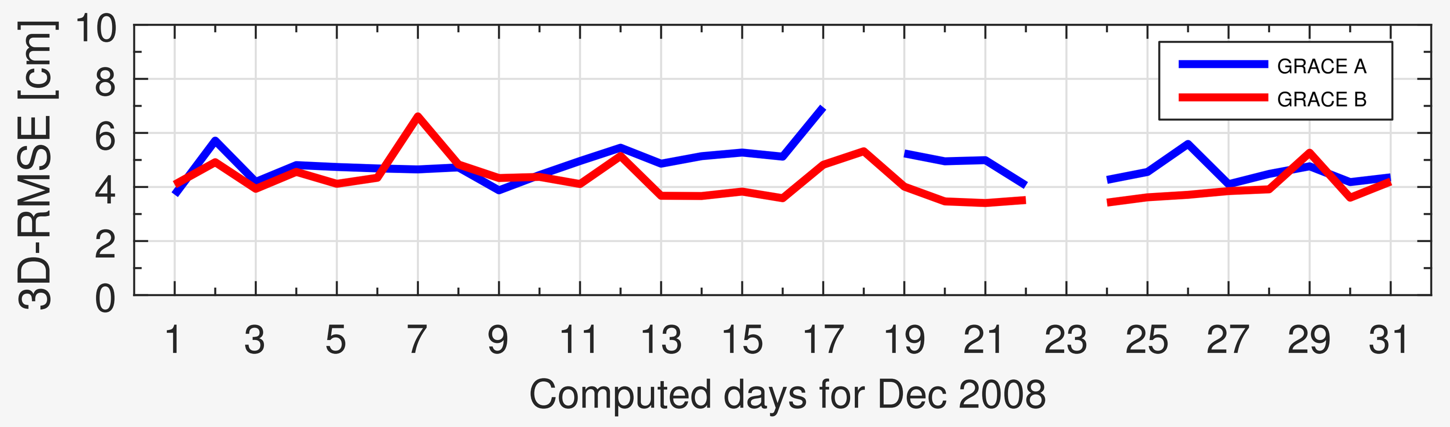

Figure 14: 3D-RMSE of IfE advanced kinematic orbit w.r.t reduced-dynamic orbit from JPL for Dec 2008

Conclusion

- Challenges for kinematic orbits arise mainly through the characteristics of the GNSS observations
- Innovative concepts were proposed such as RCM and phase only solution to overcome these issues
- Through RCM we strengthen the observation geometry, decorrelate the parameters in the adjustment, reduce the number of unknown parameters, bridge unusable epochs and improve the position residuals
- Further investigations related to our particular phase only kinematic orbit have to be made to underline the potential of this approach
- We make use of our approach of residual maps to mitigate remaining systematic errors, especially uncalibrated PCVs and near-field multipath-like signals
- Compared with a classical PPP-based kinematic orbit approach significant improvements of 36 % in 3D-RMSE were obtained by our advanced orbit
- On-going investigating and reducing of currently remaining systematics will improve the solution further on
- Comparisons to existing GRACE orbit products have to be taken with care. We intend comparisons to Satellite Laser Ranging (SLR) orbits and on the basis of gravity field solutions to show the potential of our approach

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