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Kinematic Orbits for LEO Satellites - a New Product

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Introduction:

Thanks to the high performance of the BlackJack GPS receiver flying on CHAMP, kinematic precise orbit determination (POD) has turned out to be a new method in orbit determination for Low Earth Orbiters (LEO). Kinematic POD is based on GPS measurement and does not make use of information on force models. Therefore it is independent of orbit design (e.g. satellite altitude). From that point of view, kinematic orbits are very well suited for the Earth observation satellites at very low altitudes, where air-drag and gravity become more difficult to model. With highly accurate CHAMP kinematic positions, interesting new methods are being developed nowadays to e.g. determine gravity field, validate dynamical models, or derive atmosphere density.

We determined CHAMP kinematic orbits for a period of one year. A considerable number of groups already uses these kinematic positions for validation of dynamic orbits and models and, for the first time, several groups estimate Earth gravity field coefficients based on our kinematic CHAMP positions together with the corresponding variance-covariance information, making use of the energy balance approach or the boundary value method rather than the classical numerical integration schemes. The validation of gravity field models computed in such a way showed that CHAMP kinematic positions contain high-resolution gravity information and that the accuracy of the derived gravity models is very close to that of official GRACE models. Kinematic positions with the corresponding variance-covariance information are an extremely attractive interface between the LEO GPS data and gravity field models or other information that can be derived from satellite orbits, because the simultaneous adjustment of model parameters (e.g. gravity field coefficients) and a huge amount of global GPS parameters, like GPS satellite orbits and clocks, zero- or double-difference ambiguities, station coordinates, troposphere parameters, Earth rotation parameters, etc. can be avoided.

Kinematic, reduced-kinematic and reduced-dynamic POD approaches developed based on zero- and double-differences with and without ambiguity resolution are shown. We present reduced-kinematic POD as a new approach in LEO POD. We show positioning with, what we call, "relative phase high-rate GPS satellite clocks" or GPS clocks estimated using solely phase measurements. For the first time kinematic orbits for GPS satellites are shown.

Kinematic IGS Station

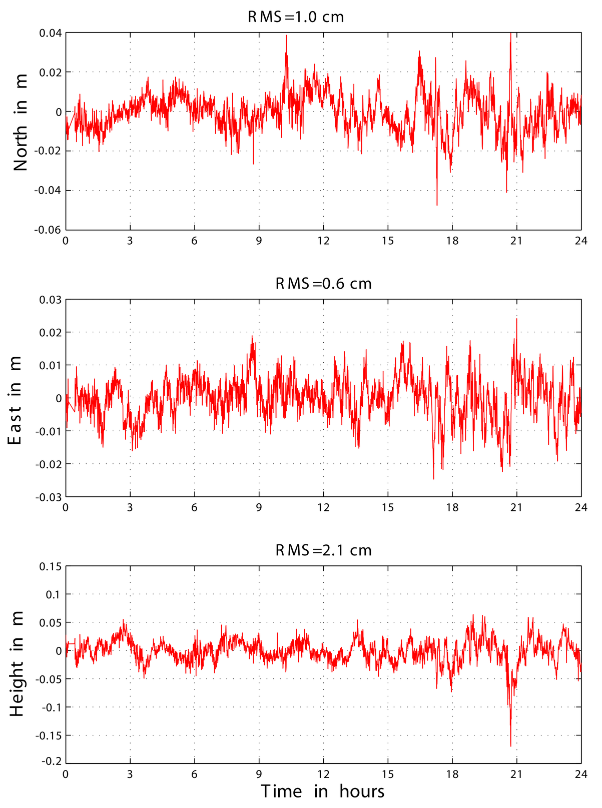


Fig. 1. Kinematic estimation of the ground IGS point GODE with respect to the fixed IGS station ALGO. Ambiguity resolved baseline with the length of 777 km, day 200/2002. All IGS products were kept fixed.

Kinematic CHAMP Satellite

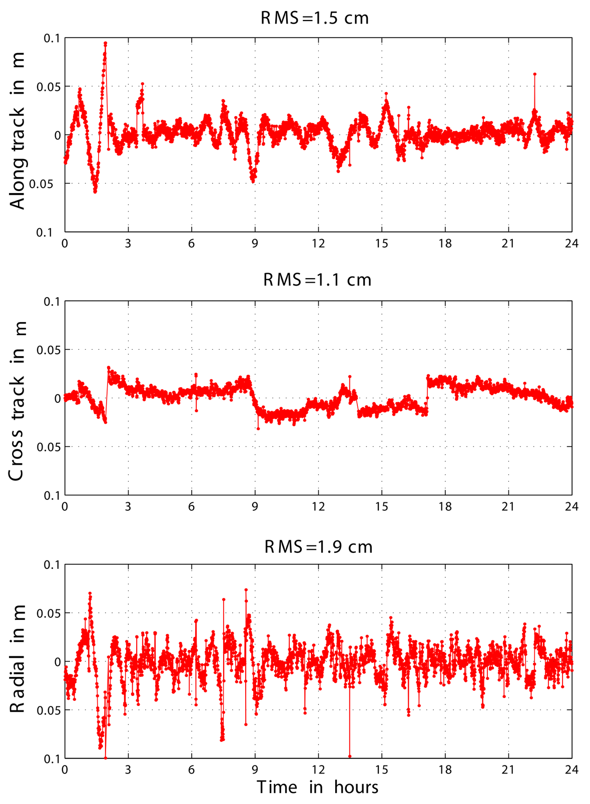


Fig. 2. Differences between CHAMP double-difference kinematic orbit and CHAMP reduced-dynamic orbit, day 199/2002. Approx. 50 stations were used to form baselines between IGS stations and CHAMP satellite.

Kinematic GPS Satellite (PRN 20)

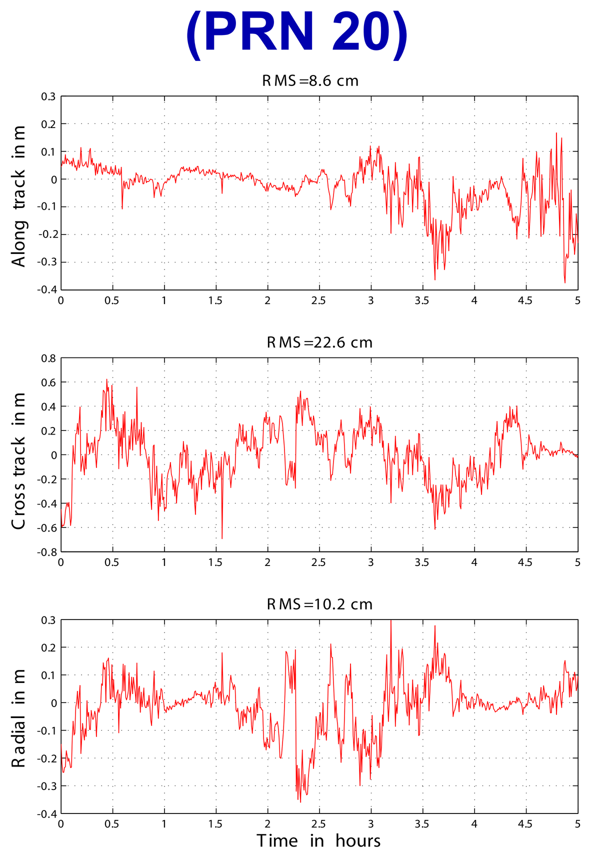


Fig. 3. Differences between kinematic and dynamic orbits for GPS satellite (PRN 20) determined using double-differences, day 200/2002. The same phase data, IGS products and models were used in both POD approaches and dynamic parameters were replaced with the epoch-wise kinematic coordinates.

GRACE Kinematic Baseline

simulated data

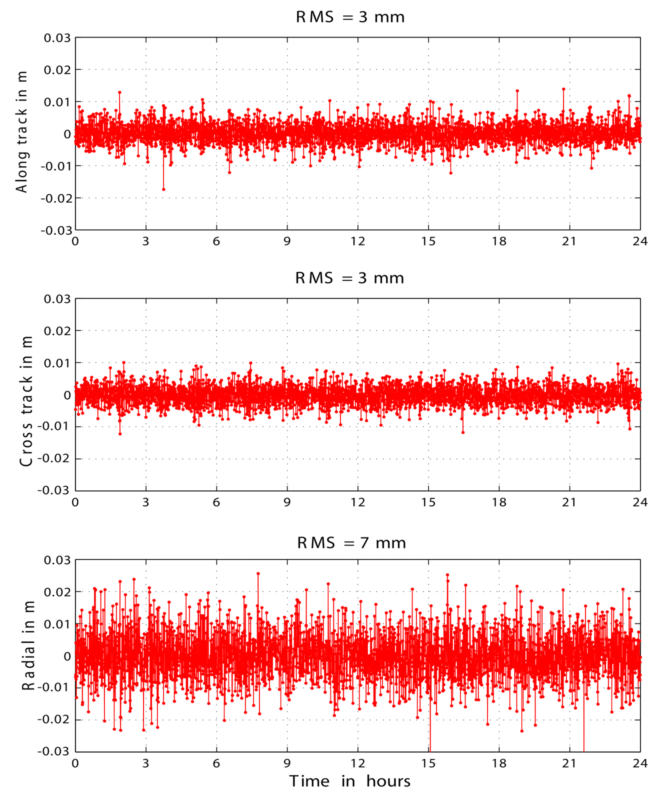


Fig. 4. GRACE kinematic baseline with ambiguity resolution based on Melbourne-Wübbena wide-laning with narrow-lane kinematic bootstrapping. Positions of the GRACE-A satellite are kinematically estimated keeping GRACE-B as fixed and compared to the true positions. The simulation scenario was similar to the measurement noise in the CHAMP data set.

CHAMP Kinematic Orbit Versus Reduced-Dynamic Orbit (GPS week 1175/2002)

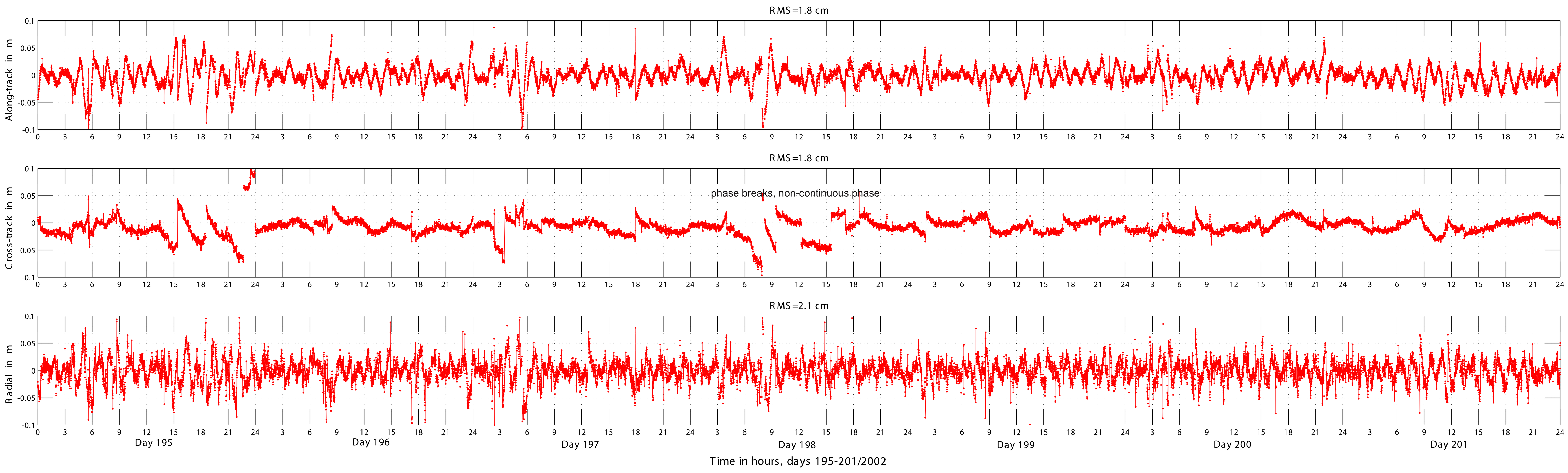


Fig. 5. Differences between CHAMP kinematic and reduced-dynamic orbit for GPS week 1175/2002. Once-per-revolution signatures can be recognised in the along-track and the radial component (air-drag modelling?)

SLR Test

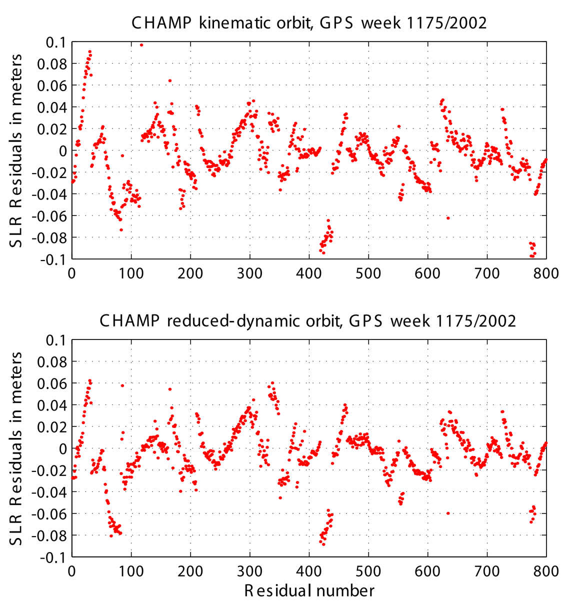


Fig. 6. SLR residuals for CHAMP kinematic (STD=2.5 cm) and reduced-dynamic orbit (STD=2.3 cm), GPS week 1175/2002. SLR residuals show a similar behaviour for the kinematic and reduced-dynamic orbit. Both types of orbits do not show any SLR system bias. SLR troposphere effects were modeled using Marini-Murray model and standard corrections like ocean loading (GOT00.2), Shapiro effect and station velocities were applied. All SLR stations and all SLR measurements were used in the orbit validation (elevation cut-off 10°).

One-Year of CHAMP Kinematic and Reduced-Dynamic Orbits

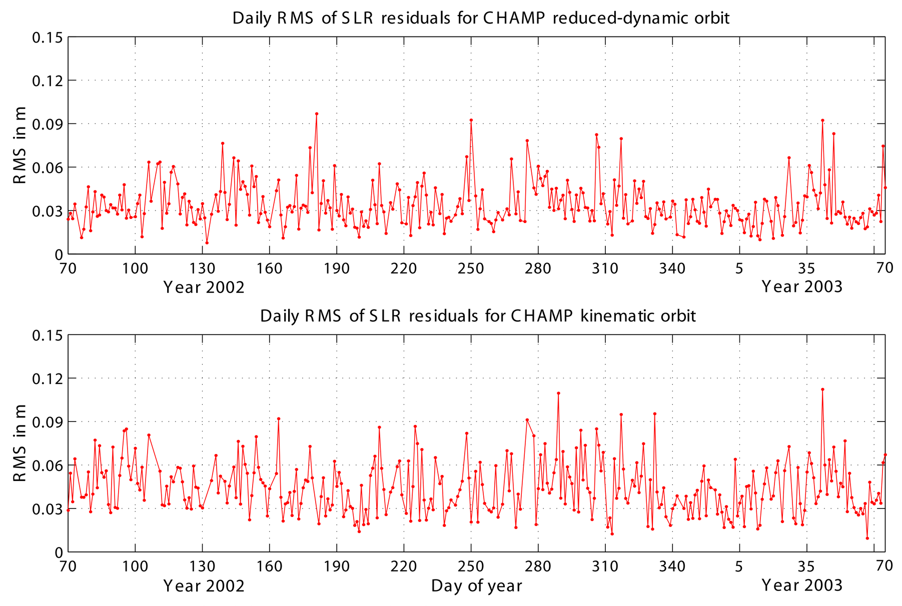


Fig. 7. Daily RMS of SLR residuals for CHAMP reduced-dynamic and kinematic orbit. Due to the data gaps in the CHAMP GPS measurements and attitude information of lower quality (data gaps, outliers) the POD accuracy is different from day to day.

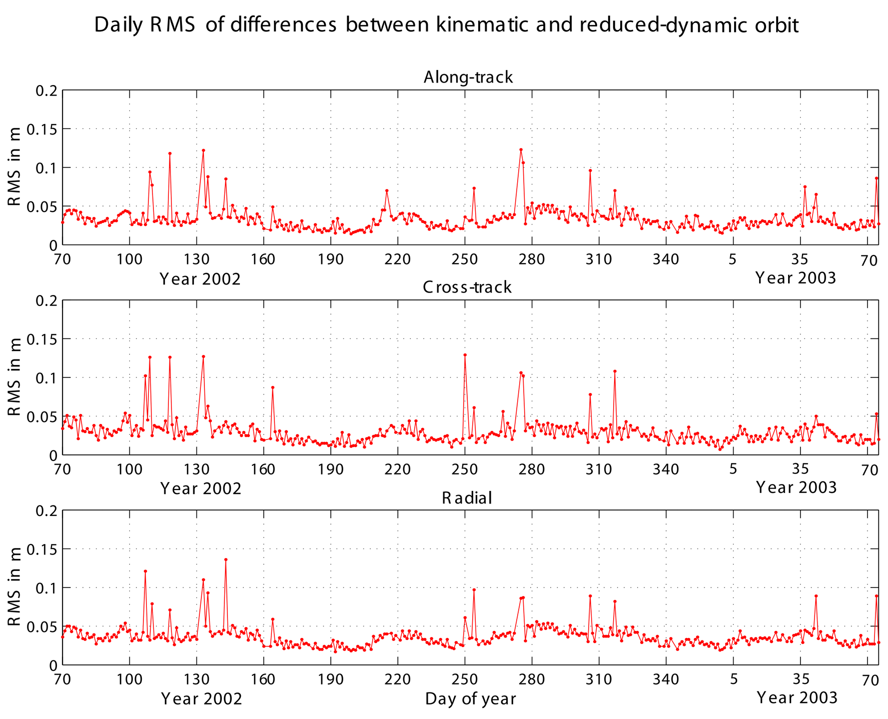
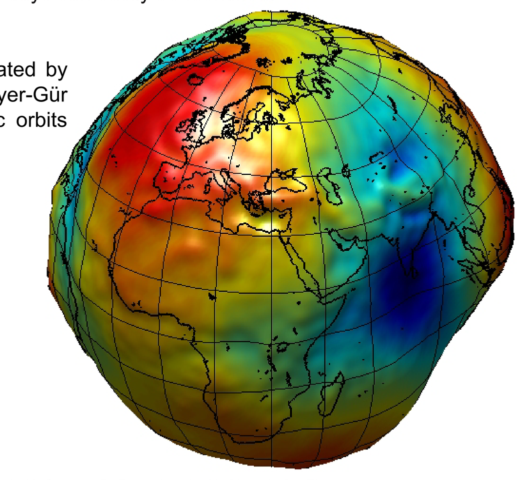


Fig. 8. Daily RMS of differences between kinematic and reduced-dynamic orbit for the period of one year. Problematic days can easily be identified.

Fig. 12. Gravity field models estimated by Gerlach et al., Földvary et al., Mayer-Gürr et al., using the CHAMP kinematic orbits presented here.



Gerlach Ch., L. Földvary, D. Svehla, Th. Gruber, M. Wermuth, N. Sneeuw, B. Frommknecht, H. Oberndorfer, Th. Peters, M. Rothacher, R. Rummel, P. Steigenberger: A CHAMP-only gravity field model from kinematic orbits using the energy integral; Geophysical Research Letters, 30(20), 2037, doi:10.1029/2003GL018025, 2003.

Földvary L., D. Svehla, Ch. Gerlach, M. Wermuth, Th. Gruber, R. Rummel, M. Rothacher, B. Frommknecht. Th. Peters, P. Steigenberger: Gravity Model TUM-2Sp Based on the Energy Balance Approach and Kinematic CHAMP Orbits, Proceedings of the 2nd CHAMP Science Meeting 2003 (accepted).

Mayer-Gürr T., K.H. Ilk, A. Eicker, M. Feuchtinger: ITG-CHAMP01: A CHAMP Gravity Field Model From Short Kinematical Arcs of a One-Year Observation Period (submitted to Journal of Geodesy)

Positioning With the Relative Phase High-Rate GPS Clocks

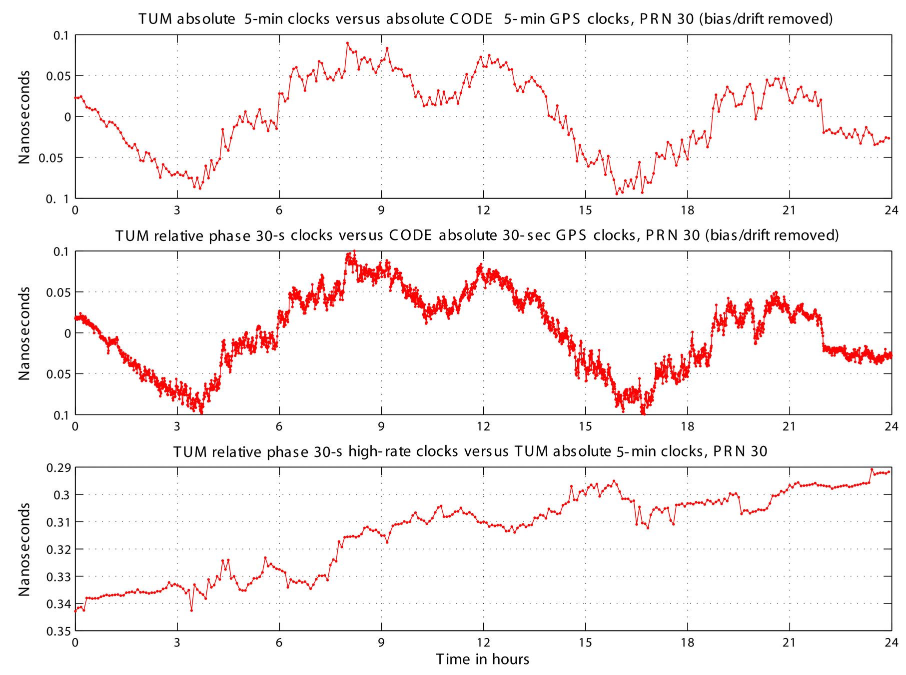


Fig. 9. The top figure shows differences between TUM and CODE 5-min clocks estimated using simultaneously phase and code measurements (absolute clocks). Since absolute clocks information is not required when POD is performed with the phase observables, GPS clocks can be estimated using solely phase measurements. This is nicely shown in the bottom figure where a clear bias and drift exists between relative 30-s phase clocks and absolute 5-min. code/phase clocks. The middle figure presents relative phase 30-s GPS satellite clocks compared to the CODE 30-s clocks. Estimation of the high-rate GPS clocks was carried out using solely phase measurements from the IGS network (45 stations) and one fixed H-maser.

Reduced-Kinematic POD

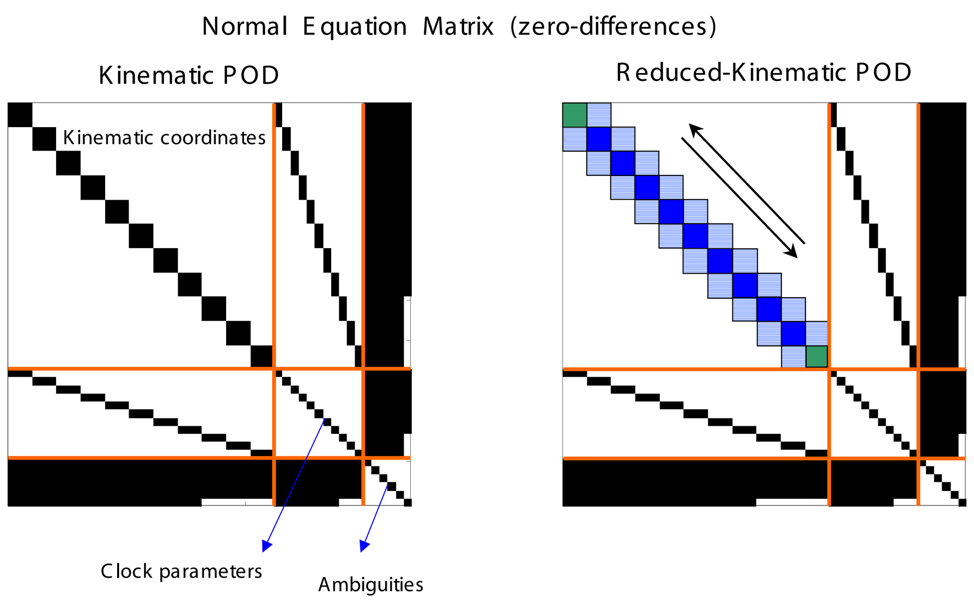


Fig. 10. Reduced-kinematic POD can be defined as kinematic POD with a priori information on dynamics, whereas in the reduced-dynamic case, dynamic POD is reduced with the geometrical information. The normal equation matrices for kinematic (left) and reduced-kinematic (right) POD based on zero-differences are shown. One can notice the block tridiagonal system on the main diagonal for the reduced-kinematic NEQs due to constraints between successive epochs in radial, cross and along track direction. *L-U* factorization with block forward elimination and backward substitution can be applied to invert NEQs.

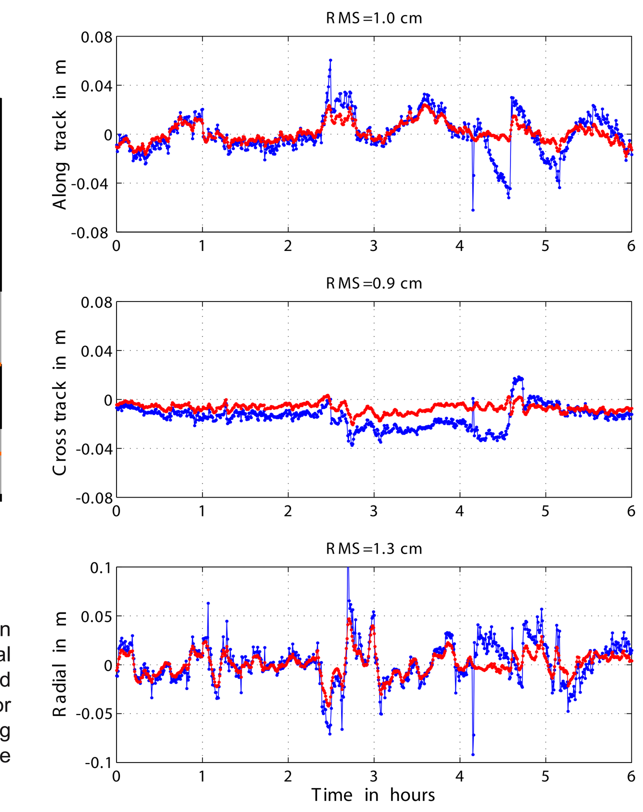


Fig. 11. CHAMP kinematic and reduced-kinematic orbit versus reduced-dynamic orbit, day 200/2002. Compared to the kinematic orbit (blue), one can see how reduced-kinematic orbit is significantly smoother (red).

Gravity Fields From Kinematic Orbits

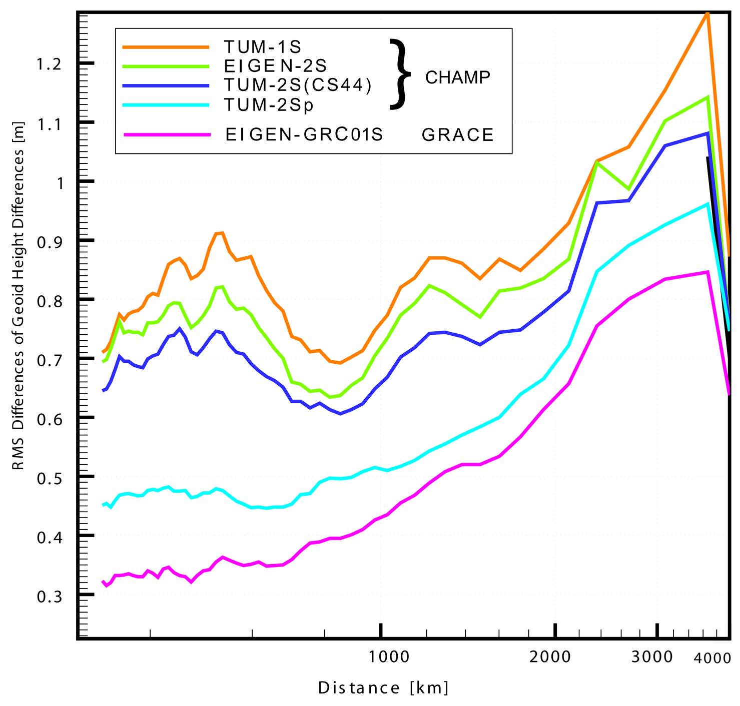


Fig. 13. The figure shows validation of the gravity models estimated using kinematic orbits presented here with the GPS/leveling points in US (5168 geoid undulations). It is obvious, that TUM-2Sp brings a considerable improvement compared to older models like TUM-1S or EIGEN-2. The accuracy is very close to the GRACE models.

CHAMP POD With Absolute GPS Antenna Patterns

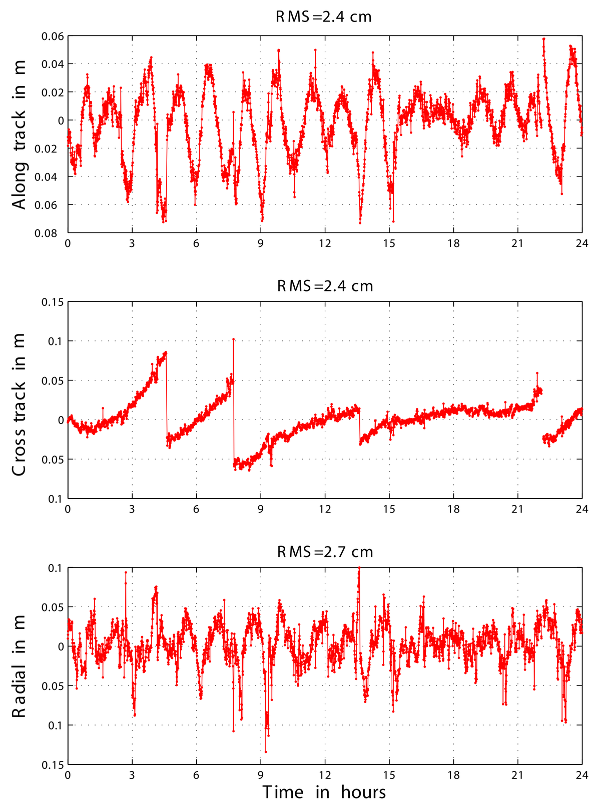


Fig. 14. Difference between CHAMP kinematic and reduced-dynamic orbit estimated using zero-differences and relative phase clocks, day 200/2002. The orbits were computed using absolute phase center offsets and patterns for antennas of CHAMP and GPS satellites.

Conclusions:

- We show that kinematic LEO orbits can be determined with an accuracy of 1-3 cm, based solely on the GPS measurements without using any information on satellite dynamics. Kinematic orbits of GPS satellites can be estimated with an accuracy of 10-20 cm.
- Reduced-kinematic POD can be defined as the kinematic POD with a priori information on dynamics, whereas in the reduced-dynamic case, dynamic POD is reduced with the geometrical information.
- Reduced-kinematic POD can be performed using relative constraints between successive epoch, reducing effects of phase breaks and weak geometry.
- Zero-difference positioning can be carried out using relative phase high-rate GPS clocks that are estimated solely with phase measurements (45 IGS stations). Due to the estimation of ambiguities without code measurements they have small offset compared to the IGS clocks. They are determined by fixing the clock information from one ground H-maser and aligned to the broadcast GPS clocks.
- When looking at differences between kinematic and reduced-dynamic orbits, one can nicely see the once-per-revolution signatures in the reduced-dynamic orbits, especially in the along-track component (air-drag modelling?).
- Kinematic and reduced-dynamic POD was carried out for one year of CHAMP data showing that highly accurate gravity information can be extracted from kinematic orbits independently of any a priori gravity information. They are determined using the energy integral or boundary value method and with an accuracy very close to GRACE models.
- Ambiguity resolution based on bootstrapping can be very successfully applied to the GRACE kinematic baseline, increasing accuracy and decorrelating ambiguities from kinematic positions.

Acknowledgements:

We are grateful to Peter Steigenberger for computing GPS satellite orbits in the framework of the IGS Reprocessing and Christian Gerlach for providing a nice picture of his geoid.