Kinematic and Dynamic Determination of Trajectories for Low Earth Satellites Using GPS

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Summary. With an increasing number of satellites carrying reliable GPS receivers orbit determination using the high precision and uninterrupted GPS tracking technique gains increasing attention. Different from other approaches for generating kinematic satellite trajectories based on zero- or double-differenced GPS observations the procedure developed at our institute uses zero-differences with differences from epoch to epoch for the phase observable. The approach is very efficient due to the elimination of the phase ambiguities. In addition it includes a sophisticated data cleaning procedure. It may also be applied to objects moving on other than Earth-orbiting trajectories.

Within the LEO Pilot Project of the IGS (International GPS Service) a CHAMP orbit test campaign has been established covering eleven days from May 20 to 30, 2001 (day 140-150, 2001). A dozen institutions are contributing to the project and compare their kinematic and dynamic orbit results within the campaign.

Key words: High Rate Clocks, Low Earth Orbiters, Kinematic Point Positioning, Data Screening, Orbit Determination

1 Kinematic Point Positioning

The kinematic point positioning procedure is based on zero-differenced GPS observations. GPS satellite orbits and clock corrections are introduced as fixed. To get precise clock corrections for the GPS satellites at a rate of 30 seconds the orbits, station coordinates, and tropospheric zenith delays are fixed on the IGS solutions of the CODE (Center for Orbit Determination in Europe) analysis center. Clock correction differences are estimated for each epoch based on the epoch-differenced phase observations from the IGS ground network and used to interpolate the precise 5-minute clock corrections computed for the IGS.

Different from other approaches for generating kinematic satellite trajectories based on zero- or double-differenced GPS observations – e.g. Švehla et al. [4] – our procedure computes the kinematic positions from code pseudoranges and position differences from epoch-differenced phase observations. In a subsequent step the two time series are combined to precise positions. An advantage of this approach being similar to [1] is its efficiency because of the epoch-wise processing with the phase ambiguities being eliminated. The normal equation matrix for the combination has a banddiagonal structure which can be inverted by a fast and simple algorithm. The neglection of correlations between the epochs, however, reduces the accuracy of the combined positions. In addition, jumps may occur in the kinematic orbit at epochs where the positions cannot be connected by phase differences because of few tracked satellites or data problems.

The computation of position differences from phase as well as the screening procedure relies on an a priori orbit. A reduced-dynamic orbit or a filtered trajectory based on code observations only is sufficient for this purpose.

2 Data Quality and Screening

Important for the processing of GPS data from LEOs is the data quality and screening. Figure 1 shows the distribution of the observations from day 339/2001 (December 5, 2001) as a function of the zenith distances for the two satellites CHAMP and SAC-C. On that day CHAMP was tracking eight GPS satellites during 75% of the day while SAC-C was tracking only up to seven satellites. During about 5% of the day the CHAMP receiver was tracking six or less satellites. These numbers are typical for the time period from 206/2001 to 065/2002. Before day 206/2001, during the IGS CHAMP orbit test campaign, the receiver was tracking satellites below the local horizon reducing the number of usable satellite observations by about 10%. Since day 065/2002 CHAMP is tracking up to ten satellites.

The screening algorithm to find unusable observations relies on an a priori orbit which may be derived from code observations only. Outliers are rejected by a majority voting algorithm [3]. The kinematic positions and position

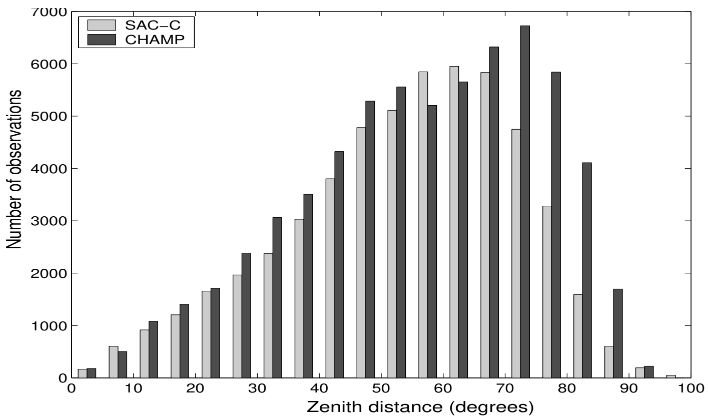

Fig. 1. Distribution of the observations for day 339/2001 vs. zenith distances.

differences are then computed using an iterative procedure. For the time period covered by the CHAMP orbit comparison campaign the screening algorithm removed about 5% of the observations of the satellite.

3 Kinematic and Dynamic Orbits

Figure 2 shows the differences between our kinematic orbit and the dynamic orbit computed by R. König at GFZ, Potsdam, for day 141, 2001. The RMS difference between the two orbits is of the order of 30 cm. The kinematic orbit shows jumps at epochs which are not connected by phase observations. The magnitude of the jumps is related to the noise of the code observations.

As a next step a dynamical orbit is fitted to the precise kinematic positions. Our procedure allows to model the non-gravitational forces (solutions A-E in Table 1) and estimate their scales factors (D, for air drag), or to introduce accelerometer observations with estimating the bias (F-I) and scale parameters of the instrument, to estimate offsets between the different arc pieces not connected by the phase to account for jumps (B, D, G, I), and to setup stochastic pulses at predefined epochs in order to account for satellite manoeuvers (C-E, H, I).

In Table 1 the results from different orbit parameterizations are listed for day 142 and 143 (May 22 and 23, 2001) together with the RMS values of the fit. Estimating the offsets between the different arc pieces (A→B, C→D, F→G, H→I) as well as setting up stochastic pulses at the manoeuver epochs (A→C, B→D, F→H, G→I) reduces the RMS values. For solution E the stochastic pulses are set up every 10 minutes which results in a reduced-dynamic orbit.

Alternatively to use the precise kinematic positions for a dynamic orbit fit, the positions determined from code and position differences from phase

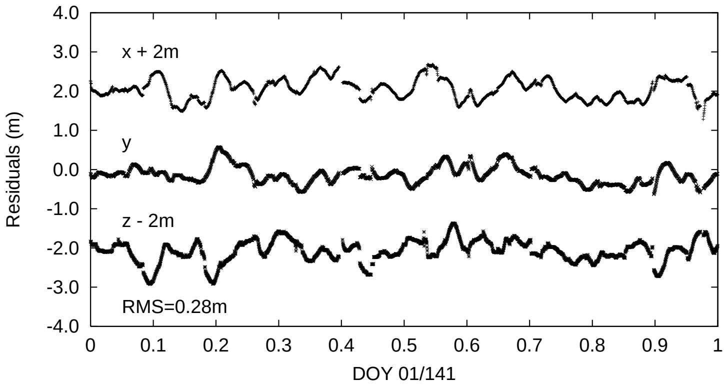

Fig. 2. Differences between GFZ dynamic and AIUB kinematic CHAMP orbit in Earth-fixed frame for day 141/2001.

Table 1. Comparison of different dynamic orbit parameterizations, RMS(m).

Solution	A	B	C	D	E	F	G	H	I
Non-grav.	mod	mod	mod	mod	mod	acc+bias	acc+bias	acc+bias	acc+bias
Empirical acc.	9	9	9	8	6	6	6	6	6
Arc offsets	-	yes	-	yes	-	-	yes	-	yes
Stoch. pulses	-	-	man	man	10min	-	-	man	man
Air drag	-	-	-	yes	-	-	-	-	-
RMS for day									
142	1.30	1.05	0.51	0.42	0.04	1.33	1.08	0.53	0.42
143	1.61	1.47	0.59	0.50	0.03	1.92	1.81	0.59	0.50

may be introduced separately with the weight of the respective observation types as pseudo-observations. Figure 3 shows the difference of a reduced-dynamic orbit (constant and once-per-rev empirical accelerations, stochastic pulses every 10 minutes) based on positions and position differences and a reduced-dynamic orbit generated by M. Rothacher and D. Švehla at Technical University in Munich. The RMS difference is between 12 and 17 cm for the eleven days of the CHAMP orbit comparison campaign.

4 Summary

The described approach allows an efficient determination of kinematic positions of LEOs and may be used for receivers moving on arbitrary trajectories, too. The currently achieved accuracy is of a few decimeters, mainly given by missing phase information introducing jumps, bad observation data which passed the screening procedure, and neglection of correlations between

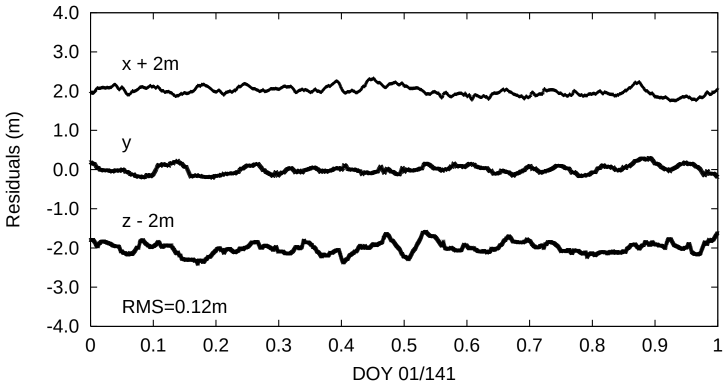

Fig. 3. Differences between reduced-dynamic CHAMP orbits from TUM and AIUB in Earth-fixed frame for day 141/2001.

epochs. The implemented dynamic orbit determination algorithm allows to deal with the jumps in the kinematic orbit, to account for manoeuvers, and to probe the range between the dynamic and reduced-dynamic regimes.

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