Modified Sidereal Filtering – Tool for the Analysis of High-Rate GPS Coordinate Time Series

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Abstract. In the error budget of high-rate GPS coordinate time series the geometry satellite – antenna plays a significant role, by means of which the repeat time interval of the identical configuration of GPS satellites must be determined. Instead of the sidereal time interval a more detailed investigation yields a smaller value, namely the so-called “modified sidereal time interval”. The exact value depends on an average of the orbit repeat period of satellites under consideration.

The recurrence period can be determined also empirically by the cross covariance function of time series of consecutive days. For the example noted above the diminution w.r.t. the sidereal time interval amounts to 10-14 seconds, and within this range being equal for position and height.

The difference reduces the root mean square error in the time series to up to half of the original value. With respect to the sidereal time interval the modified one reduces the rms again by a few percent. In the spectral domain the improvement can be seen within the range of 50 to 500 sec.

The spectrum of displacements due to waves caused by the Sumatra earthquake of Dec 26, 2004 could be determined, using 1 Hz GPS data covering Central Europe. With respect to the ground truth given by the STS-2 seismometer the agreement in sharp lines is very satisfying, particularly for the horizontal components.

Keywords. Modified sidereal filtering, high-rate GPS, Sumatra-Andaman earthquake Dec 26, 2004

1 Introduction

For the investigation of deformations of the earth’s surface the analysis of high-rate GPS coordinate time series is gaining ever-increasing importance. Especially the improved resolution in time is of interest for static deformation as well as for seismology for transient deformations by seismic waves (Bock et al. (2004)). As shown by the authors (Söhne et al. (2005)) for the Sumatra-Aceh earthquake of Dec 26, 2004, the proof of the movements of a few centimetres by seismic wave fields was even possible in more than 9,000 km epicentral distance using GPS with baseline lengths of 100 up to 1000 km and a simple band-pass filtering for periods between 250 and 10 sec, which was fortunately due to a minimum of additional disturbances at the arrival time of first onsets.

A more sophisticated approach must consider the multipath effect – an effect, which originates from the complicated interaction of reflected waves in the neighbourhood of the antenna, for more details see, e.g. Choi et al. (2004). Within the context of the analysis of seismic waves it is important that the multipath effect generates contributions also in this period range (Larson et al. (2006)). For such studies the multipath effects must be eliminated. By comparison of power spectral density of GPS time series with ground truth data we will demonstrate the success of this attempt. Basic lines of this paper follow those of Choi et al. (2004).

2 GPS Observations

Our high-rate GPS time series are basing on a 1 Hz sampling rate and cover the first 4 or 6 hours of the days Dec. 24 – 26 or 27 2004, i.e. the days 359 – 361 or 362 of the year 2004. The time scale is given in GPS time. For comparisons with STS-2 time series the leap seconds (for the year 2004: 13 sec) have to be taken into account.

The derivation of positioning time series was carried out using the Bernese GNSS analysis software version 5.0. The software features the option to output kinematic coordinates for every epoch after fixing the ambiguities for the whole session (Ihde et al. (2005)).

Fig. 1 shows the variations in the E-W component in the time interval 9750 … 11500 s after midnight (02:42:30 … 03:11:40) for the days 359 (top) up to 362 (bottom) for the baseline Kaiserslautern – Wettzell. It can be clearly seen that the anomaly (amplitude up to 30 mm, duration up to 10 min) appears in the next day approx. 250 s earlier.

Fig. 2 presents the variations in the N-S component covering the time interval 4800 … 7200 s after
Figs. 1 and 2 hint very clearly to a repetition property of the anomalies in the time series. It seems that the anomalies developed due to a multipath effect.

3 Modified sidereal filtering (MSF)

3.1 Theoretical background

Since the multipath effect is also a function of the incidence angle of the incoming wave, it depends on the geometry satellite – antenna. Two ways to identify multipath effects are to look for the repetition (1) of the same geometry or (2) of the same signatures in the coordinate variations. Item (1) is related to satellite geodesy, orbit repeat period; item (2) can be handled by cross-covariance functions in the world of time series analysis.

3.1.1 Orbit repeat period

The GPS satellite orbits were selected such to present a period of approximately one half a sidereal day to give them repeatable visibility. To guarantee this the dominant nodal drift rate must be compensated by a faster orbit repeat period. The nodal drift rate depends on $C_{20}$ of the Earth gravity field as well as the orbit parameters of the individual satellite (Seeber (1993)), i.e. the orbit repeat period is distinct for each satellite, see e.g. Axelrad and Larson (2006). An algorithm for computing these values can be found in Agnew and Larson (2006).

In the sky plot (Fig. 3) those satellites can be seen which were used for the determination of coordinates in Dec 26, 2004, time interval 01:00:00 – 02:00:00. Fig. 4 illustrates the difference between a day and the orbit repeat period of satellites mentioned in figure 3 (highlighted). Almost all satellites vary in the range 239 to 252 seconds except for PRN 24, which shows 320 seconds. For satellites visible at 01:35 the mean value (without PRN 24) of this difference is 246 s, 10 s larger than the sidereal one, i.e. the mean orbit repeat period is 10 s faster, 86154 s. To handle a time interval, an average shift of the observations of 246 s for the days 360 and 492 s for the day 359 has been applied. A good coincidence of the long-term variations can be observed after the shifts.

Fig. 1 Compilation of coordinate variation (E-W-component) for four consecutive days (359 … 362 of year 2004 (top to bottom)) demonstrating the repetition character. The deviation (duration up to 600 sec, maximum range up to 30 mm) appears for the following day approx. 250 sec earlier than in the preceding one.