Combination of Ground Observations and LEO Data

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Introduction

The idea of the Integrated approach is to determine the orbits of GPS satellites and Low Earth Orbiters (LEOs) as well as Earth system parameters in a common orbit determination and parameter estimation process (see Zhu et al., 2004). Thus all available space geodetic observations are combined on the observation level considering all correlations. Thereby the high-orbiting GPS satellites provide stability to the whole configuration whereas the LEOs scan the Earth's gravity field very densely with a high temporal resolution. Furthermore, the feasibility of simultaneously estimating the Earth's geometry – represented by a ground stations polyhedron – and the Earth's center of gravity is investigated.

There are already proofs of the integrated method delivering more accurate results than a corresponding two-step procedure where the orbit determination for the GPS satellites and for the LEOs is done in two subsequent steps. The time span investigated has been extended to almost the full year 2004, as well the constellation of satellites involved has been enlarged step by step leading to a configuration of GPS ground stations, GPS satellites, and the LEOs CHAMP, GRACE-A, GRACE-B.

Constellations Processed

In this context, the constellation of the orbit determination and parameter estimation processes is mainly characterised by the observational data used, the satellites involved, and the constraints imposed on certain estimated parameters.

The data used comprise GPS/ground measurements (from the IGS and GFZ GPS networks), GPS/SST measurements (from the on board Precise Orbit Determination receivers), Satellite Laser Ranging normal points (SLR, from the ILRS network), K-band range-rate measurements (from the GRACE-A/-B intersatellite link), measured accelerations (from the LEO on board accelerometers), and measured attitude (from the LEO on board star sensors).

The constellations assembled and processed all include the ground station network. Concerning the satellites the constellations so far included a GPS/CHAMP configuration (in integrated mode), a GPS/CHAMP configuration (in two-step mode), a GPS/GRACE configuration (in integrated mode with and without K-Band), a GPS/CHAMP/GRACE configuration (in integrated mode with and without K-Band).

The processing is nominally subdivided into periods of 24 h length (processing periods). In case of K-band data gaps the processing periods can be less than 24 h.

The parameters estimated comprise the positions of the ground stations, the harmonic coefficients of the Earth's gravity field up to degree and order two, the residuals of the observations, and auxiliary parameters for adjusting the force model acting on the satellites and those for correcting the observations. Outside the proper orbit determination and parameter estimation process for each processing period a 7-parameter Helmert transformation has been carried out between the estimated and the a priori station positions yielding a 3D translation, a global scale, and three rotation angles.

In order to keep the solution near to the a priori values that are assumed to be good there are imposed constraints on the ground stations' positions and on the harmonic coefficients in form of pseudo-observations with a priori sigmas of equivalently 10 cm on the Earth's surface.

Improvements by the Integrated Method

Comparing a GPS/CHAMP configuration in a two-step mode and in an integrated mode reveals better results for the integrated mode. This is clearly indicated by a smaller RMS of the GPS/SST phase residuals that decreases from 0.95 cm to 0.51 cm as well as by a reduced bias (from –3.7 cm to 2.6 cm) and a reduced standard deviation (from 6.2 cm to 1.0 cm) of the z-translation of Helmert transformations.

Between a GPS/CHAMP and a GPS/GRACE configuration, both in integrated mode, the GPS/GRACE case leads in general to reduced scatter in the time series as the twin GRACE satellites – even without using K-band data – act as »two times CHAMP« with double the amount of GPS/SST data.

Going from a GPS/GRACE configuration to GPS/CHAMP/GRACE, both using K-Band data, several improvements appear. As shown by Fig. 1 the standard deviation in the z-translation of Helmert transformations decreases significantly from 6.81 cm to 0.74 cm. Also the standard deviation of the scale of Helmert transformations is lessened from 1.44 ppb to 1.01 ppb. Concerning the C_{10} harmonic coefficient (i.e. the z-component of the geocenter) the standard deviation is reduced from 7.45 cm to 1.46 cm, see Fig. 1. The rather strange shift in C_{20} between the GPS/GRACE configuration and the SLR-only GFZ Lageos solution (see König et al., 2006, and König et al., 2007) is reduced, as can be seen in the middle time series shown in Fig. 2. Moreover, comparing a GPS/CHAMP/GRACE configuration with and without K-band the offset in C_{20} is further reduced from about –4.841650E-04 to –4.841655E-04, as shown in the lower graph of Fig. 2.

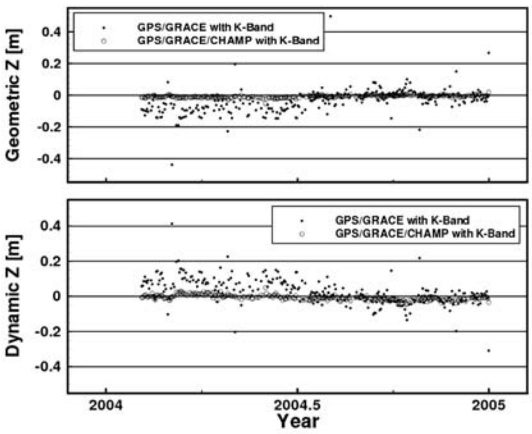

Figure 1: Z-translation of Helmert transformations (»Geometric Z«) and C_{10} harmonic coefficient (»Dynamic Z«) for a GPS/GRACE and a GPS/GRACE/CHAMP configuration

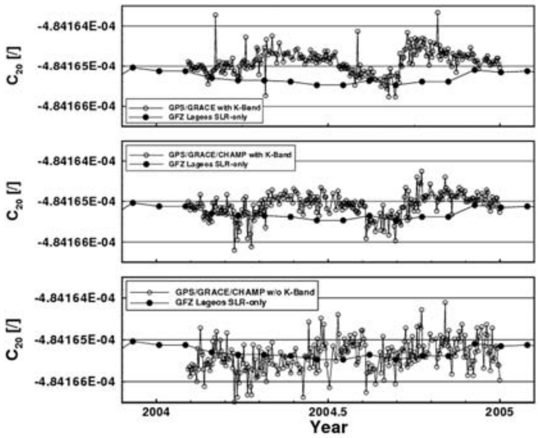

Figure 2: C_{20} time series for different integrated configurations, and for the SLR-only GFZ Lageos solution

Level of Accuracy Reached

Recently, tests have been made changing the original scheme of weighting GPS ground and SST data. For the weighting scheme yielding best results the level of accuracy is presented in the following.

A suitable measure for assessing the accuracy of satellite orbits is the RMS of residuals of laser observations that have been used with a very low weight. Also the RMS of GPS phase residuals indicates the internal accuracy of the determined orbit configuration. The global RMS of laser residuals ranges for the LEOs between 3.5 cm and 4.1 cm, and for the GPS satellites PRN 5 and PRN 6 it is 7.7 cm and 8.0 cm, respectively. The global RMS of GPS phase residuals for ground stations comes out at 0.56 cm, and for the LEOs at around 0.4 cm.

The accuracy of the estimated geometric frame can be characterised by the standard deviations of the time series of its translational components, of its scale, and of its rotation angles. The standard deviations of the translational x- and y-component are 1.24 cm and 1.46 cm, respectively, whereas the time series of the z-translation is rather stable with a standard deviation of 0.74 cm. The scale is rather stable, too, at a standard deviation of 1.01 ppb. The time series of the rotational angles turn out to be 0.68 cm, 0.71 cm, and 0.16 cm for the rotations about the x-, y-, and z-axis, respectively. Thus, the orientation of the estimated geometric frame is very stable, especially around the z-axis.

The dynamic frame is represented by the dynamic origin, the so-called geocenter, and the dynamic scale. The dynamic scale is given by the C_{00} harmonic coefficient, whereas the dynamic origin is given in x-, y-, and z-direction through the C_{11} , S_{11} , C_{10} harmonic coefficients, respectively. The time series of C_{00} does not yet show reasonable behaviour probably due to very high correlation with radial accelerometer biases. Nevertheless, it acts as an indicator of outliers, and it can be fixed by subsequent calculations on normal equation basis. The geocenter turns out to be rather stable with standard deviations of about 1 cm in all three components. First tests indicate that imposing global constraints on the ground stations positions in form of no-net translation, no-net rotation, and no-net scale conditions delivers geocenter time series showing a certain structure that is probably suited for geophysical interpretation.

Conclusions and Future Activities

As shown there are significant improvements detectable by changing an orbit determination and parameter estimation process from a two-step mode to an integrated mode. Even within the integrated method it helps significantly to enlarge the number of LEOs incorporated. These results are clearly confirmed by reduced standard deviations in the geometric and dynamic z-components. Concerning the C_{20} harmonic coefficient there is a shift introduced with respect to the GFZ Lageos solution that is obviously a K-band effect. In this case as well it is very helpful to incorporate another LEO in form of CHAMP reducing this shift.

In order to impose not more constraint on the parameter adjustment as necessary it seems to be worthwile to replace the constraints currently applied individually to a broad set of parameters by global constraints that exactly remove the datum defect. Thus, unnecessary constraint would be avoided that might distort the estimated parameters.

Literature

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