Recent Developments in CHAMP Orbit Determination at GFZ

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Summary. The GeoForschungsZentrum Potsdam (GFZ) operationally provides CHAMP orbit products for various purposes. Here the rapid and ultra-rapid orbits are highlighted. Significant developments in Precise Orbit Determination (POD) for Low Earth Orbiters (LEOs), in particular SAC-C and GRACE besides CHAMP, are described. GFZ also started to generate CHAMP-like rapid orbits for SAC-C with good accuracy. Furtheron improved LEO orbit accuracies are demonstrated by simultaneous orbit solutions of the GPS satellites and one or more LEOs in an integrated approach.

Key words: CHAMP, SAC-C, GRACE, GPS, Precise Orbit Determination

1 Introduction

The GeoForschungsZentrum Potsdam (GFZ) runs a science data system in the CHAMP mission [1] ground segment [2] that produces standard orbit products servicing e.g. the mission objectives i.e. gravity field and magnetic field evaluation and atmospheric and ionospheric applications. Standard orbits are firstly CHAMP orbit predictions (the PDO products) for ground net antenna steering, SLR ground station pointing, mission planning and data preprocessing. In [3] procedures and results are given. The second type of standard orbit is the Rapid Science Orbit (RSO) as input to magnetic field and atmospheric and ionospheric processors. Goals are laid down in [4], achievements are reported in [5]. The third type is the Ultra-rapid Science Orbit (USO) being of use for the evaluation of radio occultations for numerical weather prediction application. Finally the Post-processed Science Orbit (PSO) results in the course of gravity field recovery work as e.g. in [6].

In the beginning of the mission, POD of CHAMP was a challenge, see the articles refering to POD in the proceedings of the first CHAMP science meeting in 2002 [7]. Meanwhile CHAMP orbit accuracies are in the few centimeter range reported by various groups e.g. in this issue, and also shown in the sequel. In the following, focus is put on the RSO and USO for CHAMP: the RSO is mainly viewed in its historical evolution in terms of accuracy, the USO being accurate to the centimeters from its invention, is mainly viewed in its latency which by intention should be very small. Further on a RSO type of orbit for the SAC-C satellite is introduced and characterized in terms of accuracy. Finally an example of the new and promising approach of the integrated adjustment of various types of observations from a multitude of high and low altitude satellites [8], i.e. the GPS satellites, CHAMP, SAC-C and the GRACE satellites, is presented with emphasis on LEO orbit improvement.

2 CHAMP Rapid and Ultra-rapid Orbits

The RSO is generated with a latency of 17 hours on a day by day basis. It includes CHAMP 30-s ephemerides of two 14-h arcs overlapping by two hours covering the time between 10 pm the day before the previous day and 0 am the current day and one GPS 1-d arc with 300-s ephemerides and clocks for the previous day. The CHAMP orbit accuracy is measured by SLR measurements. Fig. 1 displays on its left side the development of the accuracy from the beginning of the production of the RSOs in March 2001, with slightly more than 20 cm RMS of SLR residuals down to the 4 cm level nowadays. The improvement is due to newer gravity field models updated by more CHAMP data and some tuning of the adjustment process. It should be noted that the SLR RMS values are reported as is with no outlier rejection applied. Therefore the moving mean of the RMS values indicated by the thick line in the left part of Fig. 1 gives rather a pessimistic assessment of orbit accuracy. It should also be noted that the SLR RMS gives a measure of position accuracy of the orbit as the SLR observations from ground to CHAMP cover all axis directions if the sample is large. Therefore the 1-D accuracy of the RSO or the accuracy per coordinate can be said to be slightly above 2 cm, i.e. 4 cm divided by $\sqrt{3}$, nowadays.

The GPS orbits obey an accuracy of 8 cm per coordinate assessed from comparisons with the IGS [9] rapid orbit (IGR). The right hand side of Fig. 1 gives the 1-D differences (RMS of the position differences divided by $\sqrt{3}$) and a moving mean of the point values indicated by the thick line.

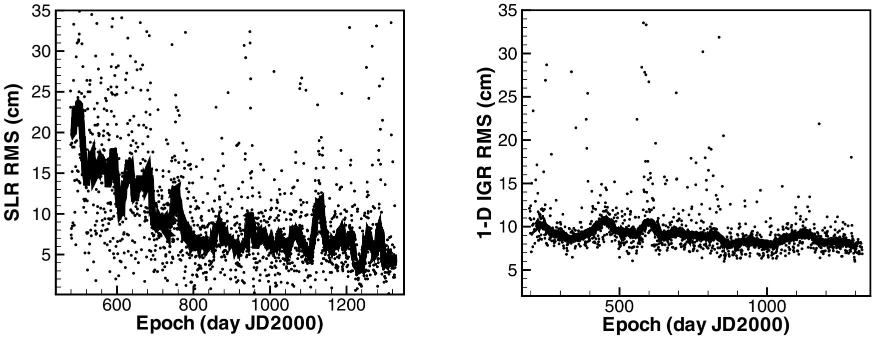

Fig. 1. CHAMP and GPS RSO Orbit Accuracies

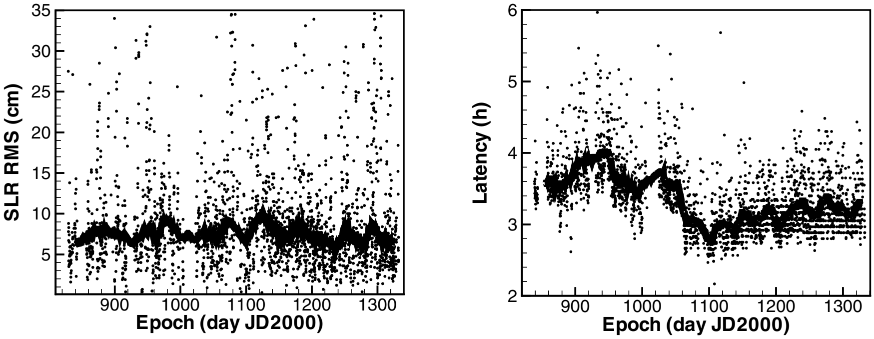

Fig. 2. CHAMP USO Orbit Accuracy and Latency

The USO is generated eight times per day at three hour intervals. As in case of the RSO, the GPS orbits contain 300-s ephemerides and clocks spanning one day, the CHAMP orbits contain 30-s ephemerides covering the last 14 hours of the GPS arc. Accuracies of the GPS orbits are 8 cm per coordinate as in the case of the RSO. The accuracies of the CHAMP orbits are slightly worse than in the RSO case. They size at 5 cm per coordinate as derived from the SLR residuals displayed on the left hand side of Fig. 2.

The USO was invented as a fast available orbit product in April 2002 as input to the rapid processing of radio occultation measurements [10]. Its latency, i.e. the difference in time between its availability for the users and its last time tagged ephemeride (covered by observations, not predicted), lies at 3 hours as displayed on the right hand side in Fig. 2 by the thick line representing the moving mean of all latencies ranging at the 3 hours level since some months.

3 SAC-C Orbits

The generation of SAC-C orbits started in July 2003 for particular periods of the SAC-C mission [11] on demand by the GFZ occultation processing group. This resulted in occultation products similar in quality to CHAMP occultation products [12]. Fig. 3 shows two quality measures for the assessment of the SAC-C orbit accuracies. Unfortunately there are no SLR observations from ground to SAC-C that could be used as an absolute measure of position accuracy. Instead we try an assessment by substitute means as the comparison of our orbits to the orbits produced by JPL [13] shown on the left hand side of Fig. 3. The mean difference in position is 12 cm with no bias detectable.

On the right hand side of Fig. 3 the standard deviations of the initial position parameters show globally 7 cm per coordinate axis. Interpreting these results with the experiences from CHAMP, the accuracy of the SAC-C orbits may assessed to lie below 6 cm per coordinate.

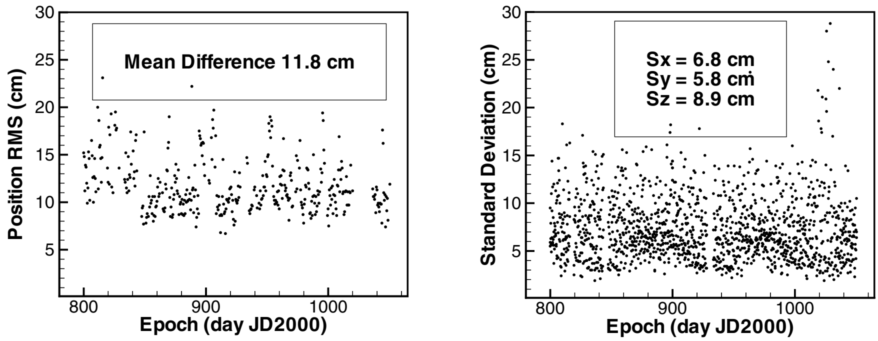

Fig. 3. SAC-C Orbit Accuracies

4 Integrated Orbit Adjustment for CHAMP, SAC-C, GRACE and the GPS Satellites

Integrated POD means processing of GPS code and phase observations from ground stations and from space-borne receivers together with all or some of all available mission data other than GPS. In this chapter we mix GPS ground data with CHAMP, SAC-C and GRACE data with focus on effects on POD of the LEO satellites. The integrated adjustment of GPS ground and space-borne observations can also be called 1-step solution in contrast to the conventional procedure where the GPS orbit and clocks are firstly solved, then fixed and then the LEO orbit is derived based on the space-borne GPS data in a second step (2-step solution).

In [8] it is shown that the integrated POD of the GPS and GRACE satellites yields, besides improved GPS ephemerides and Earth reference frame parameters, more accurate GRACE orbits. Table 1 compiles results for the CHAMP and SAC-C satellites where two 1.5-day arcs beginning of May 2002 demonstrate the improvement on behalf of the orbital fits of GPS and SLR observations. The SLR measurements are downweighted in the POD process in order to gain an independent quality parameter.

Table 1. Improved LEO orbits by the integrated adjustment

Observation Type	RMS of Orbital Fit CHAMP 2-step (cm)	n	1-step (cm)	n	SAC-C 2-step (cm)	n	1-step (cm)	n
Code	73.89	60368	72.28	60367	124.00	54231	122.48	54230
Phase	2.55	60368	0.73	60367	2.91	54231	1.42	54230
SLR	5.97	264	5.04	264	-	-	-	-

Table 2 compiles results for the integrated POD of the GPS constellation with CHAMP plus one or more LEOs, the GRACE satellites and/or the SAC-C satellite. Table 2 seems to show that adding more LEOs does not improve

Table 2. CHAMP orbit quality by the integrated adjustment with additional LEOs

Observation Type	RMS of Orbital Fit CHAMP (cm)	n	SAC-C (cm)	n	GRACE (cm)	n
GPS + CHAMP + SAC-C:						
Code	72.33	60369	122.47	54231		
Phase	0.74	60369	1.42	54231		
SLR	5.19	264	-	-		
GPS + CHAMP + GRACE:						
Code	72.30	60369			47.70	129151
Phase	0.74	60369			0.61	129151
SLR	5.26	264			4.77	297
GPS + CHAMP + SAC-C + GRACE:						
Code	72.30	60369	122.46	54231	47.73	129152
Phase	0.74	60369	1.43	54231	0.61	129152
SLR	5.24	264	-	-	4.70	297

individual LEO orbit accuracies. However the distribution of the residuals of the space-borne observations is skew. The reason could come from the unique weighting of the ground and space-borne GPS observations where the number of ground observations is more than 10 times the number of the space-borne observations. Therefore further analyses need to be carried out.

5 Conclusions

GFZ operationally generates Rapid and Ultra-rapid Science Orbits within the CHAMP ground segment: the RSOs and the USOs. The CHAMP RSO accuracies have greatly improved over time to the 2 cm range nowadays. The USO accuracy is slightly worse however the orbits are delivered eight times a day three hours later than the latest observation in the orbit. GFZ also generates RSO-type SAC-C orbits with approximately 6 cm accuracy for occultation data processing. The integrated adjustment of ground and space-borne observation allows a considerable enhancement of LEO orbit accuracies. Additional LEOs in the integrated case seem not to increase individual LEO orbit quality.

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