Remarks on CHAMP Orbit Products

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Summary. The GeoForschungsZentrum Potsdam (GFZ) runs an operational system for the CHAMP mission that provides precise orbits on a regular basis. Focus is put on recent analyses and achievements for the Rapid and Ultra-rapid Science Orbits.

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

1 Introduction

Since the beginning of the CHAMP mission (Reigber, 2005) in 2000, the GeoForschungsZentrum Potsdam (GFZ) operationally provides precise orbits. These products comprise orbit predictions (the PreDicted Orbits or PDOs), rapidly available orbits (the Rapid Science Orbits or RSOs and the Ultra-Rapid Science Orbits or USOs), and offline generated orbits (the Post-processed Science Orbits or PSOs). All these routine orbits are dynamically integrated and differentially corrected for certain parameters to fit to the observations being available at the time of generation and being appropriate to meet the objectives the orbit is intended for. The orbits are provided at different frequencies, latencies, and accuracies depending again on their intention. And they are published at the CHAMP data center at GFZ (ISDC, 2001).

Developments in CHAMP Precise Orbit Determination (POD) have recently been discussed in König et al. (2005). The following concentrates therefore on newest improvements in accuracies and latencies, on new considerations regarding accuracy assessments of the RSOs of the GPS satellites, and on the accuracy of GRACE RSOs which have been invented newly to support radio occultation analysis with GRACE enhancing the CHAMP and SAC-C data set. Also given are some tests on the impact of ambiguity fixing and dense GPS clocks. These approaches are due next for the upgrade of the operational processing system.

The instruments of CHAMP provide data for use in POD, such as space-borne Global Positioning System (GPS) Satellite-to-Satellite Tracking (SST) observations, onboard accelerometer measurements, attitude, thruster firing and other POD relevant information from the housekeeping data. The ground based data are GPS data of the CHAMP low latency network, other ground GPS data from the International GNSS Service (IGS, see Beutler et al. (1999), IGS (2005)), and Satellite Laser Ranging (SLR) data from the International Laser Ranging Service (ILRS, see Pearlman et al. (2002), ILRS (2005)). The same holds true for the GRACE satellites, where however the SST observations only are exploited for the RSO. K-band intersatellite range observations as well as the attitude etc. data are omitted because they do not arrive in time. Also in case of SAC-C we must rely on space-borne GPS observations alone.

In all POD applications described in the following, the data are evaluated by GFZ's EPOS-OC (Earth Parameter and Orbit System - Orbit Computation) software system in version 5.4 at the time of writing this.

2 CHAMP Rapid and Ultra-Rapid Orbit Products

Modelling standards and earlier quality results for the CHAMP RSO and USO are given e.g. in Michalak et al. (2003). Recent efforts concentrated on improving and accelerating the pre-processing system. They resulted in more accurate GPS orbits with lower latency. Fig. 1 shows the comparison of the GPS RSO orbits to IGS Rapid Orbits (IGRs) after having applied a Helmert transformation in terms of Root Mean Square (RMS) values of position differences per axis, Fig. 2 the comparison of the GPS USOs to the IGRs. The IGRs are taken as a reference as IGS claims that their accuracy is better than 5 cm (IGS, 2005). Improvements concerned the optimization of the selection of approximately 50 stations of the GPS ground network. In effect since September 20, 2004, (marked by a dashed vertical line in Fig. 1 and 2), indeed less outliers can be noticed for both the RSO and the USO. Currently the GPS RSO shows 7.5 cm RMS versus IGR, the USO 8.5 cm. The USO is slightly less accurate because it is generated with a latency of approximately two hours after the last observation versus a latency of 17 hours for the RSO (the IGR also comes with a latency of 17 hours). Therefore the set of observations for the USO may lack data from some receivers, making the ground station network less optimal.

A validation of the RSOs of the GPS satellites PRN G05 and PRN G06 by SLR observations is performed for orbits since the beginning of year 2004. For that the GPS based orbits are fixed and compared to the SLR observations. Eventually the SLR residuals are compiled in Fig. 3. They exhibit a systematic bias of -5 cm, their standard deviation is 4.9 cm. The bias here is consistent with previously published results (e.g. Urschl et al. (2005)). Con-

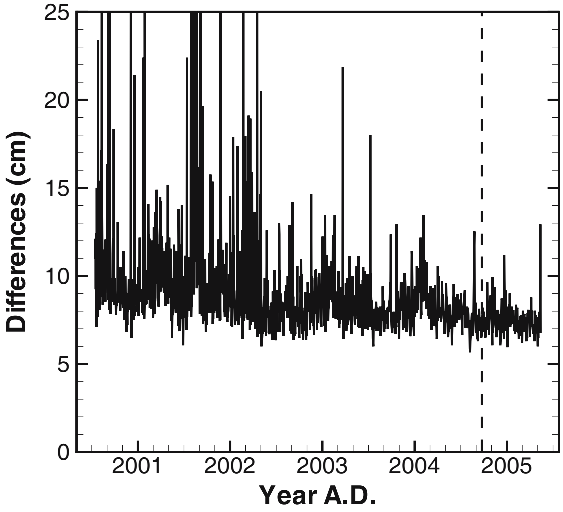

Fig. 1. Comparison of the GPS RSO to the IGR

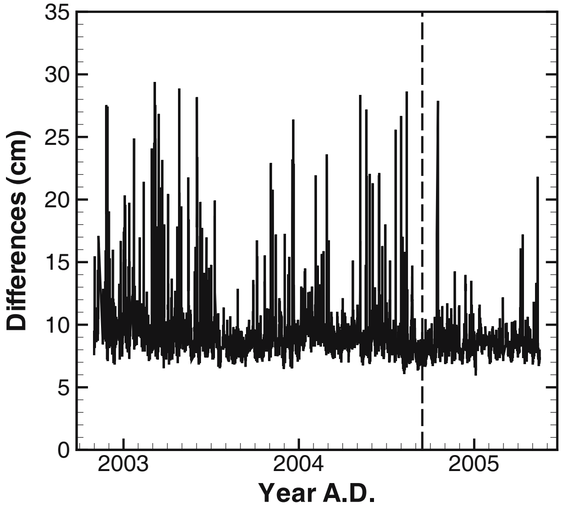

Fig. 2. Comparison of the GPS USO to the IGR

cluding from the SLR validation, a radial accuracy of 5 cm of the GPS RSOs can be assessed.

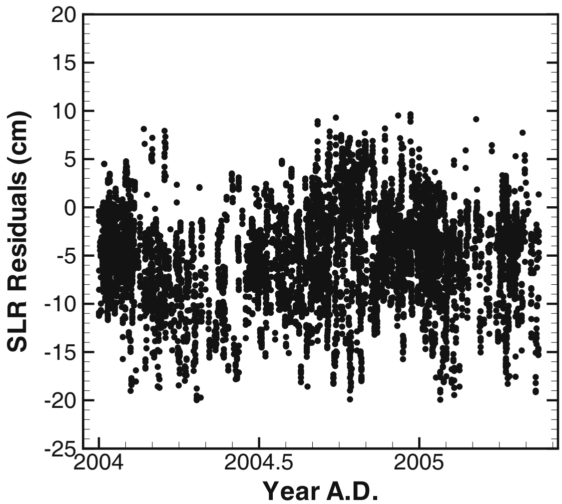

Fig. 3. SLR validation of the RSOs of PRN G05 and PRN G06

For the determination of CHAMP RSO and USO orbits, the respective GPS RSO and USO orbits and clocks are fixed. The resulting accuracies of the CHAMP RSO orbits can again be assessed by SLR validation. For the recent period the RMS is around 5.5 cm. It should be noted here in general, that the SLR data are taken as is, i.e. the RMS values can be contaminated by outliers. In addition, the SLR observations can be located at the beginning or at the end of an arc, which, due to the known dissipations of dynamical orbits at those periods, increases the RMS values as well.

A second assessment of CHAMP RSO accuracy is performed by sampling the position differences of subsequent orbits in the middle of the 2-hour period where the orbits overlap. The recently computed mean of the sampled position differences amounts to 5.0 cm. This is in good agreement with the SLR RMS and validates therefore the possibility to use the overlap analysis as accuracy assessment.

SLR validation and overlap analysis are also used to asses the accuracy of the CHAMP USO. The global SLR RMS is 7.4 cm. This is larger than in case of the CHAMP RSO due to its dependency on less accurate GPS USO orbits and because of more frequent occurences of gaps in the CHAMP SST observations. In Fig. 4 the position differences and their medians of overlapping arcs at epochs distant by 0 to 2 hours from the end of the preceding arc are given. The most critical part of the CHAMP USO orbit is its end, the last 15 minutes, where the median values are quite large, between 13 and 29 cm.

The main reason is found with poor accuracies of GPS USOs for the last 1 hour of the arc due to lacking data. Meanwhile an effort has been started to improve the acquisition of GPS ground data covering the last 1-2 hours of the GPS USO.

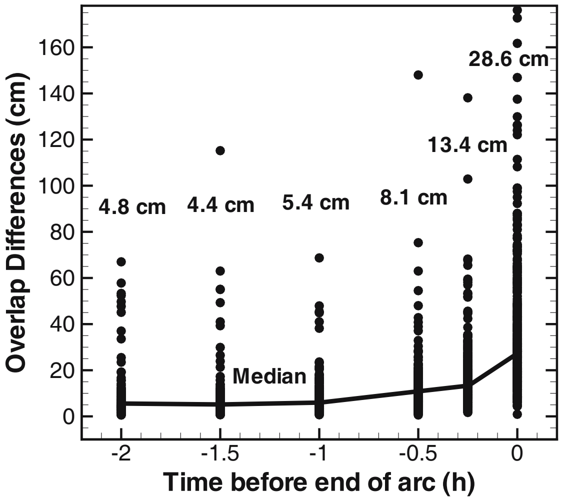

Fig. 4. CHAMP USO orbit accuracies

The GPS and CHAMP USOs are produced as pre-requisite for occultation data processing, which in turn generates atmospheric profiles or related products for use in Numerical Weather Prediction (NWP). The age of input data to NWP applications must not exceed three hours. The latencies of the CHAMP USO are given in Fig. 5. The recent improvement of pre-processing procedures by parallel acquisition and pre-processing of GPS ground data introduced on April 20, 2004, resulted in a reduction of the latency from 3.5h to 2.2h in mean. Further reductions are still possible by switching from a 3-hourly processing interval to dump-dependent processing. In case of CHAMP, the polar receiving station has view of the satellite during each revolution, i.e. approximately each 1.5 hours. Then the onboard data, the GPS SST observations etc., can be sent to the ground or dumped respectively.

3 SAC-C and GRACE Rapid Orbit Products

Recently the CHAMP RSO processing system was extended to generate orbits for three more occultation measuring satellites: SAC-C, GRACE A and GRACE B. The SAC-C satellit has no SLR reflector, so for accuracy assessment the overlap values only are available. The results are given in Table 1.

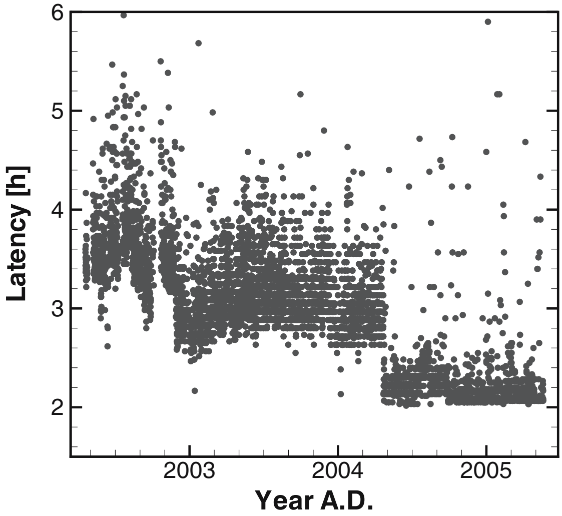

Fig. 5. CHAMP USO latencies

The mean overlap position difference 5.4 cm is close to the value for CHAMP, i.e. 5.0 cm. Since the modelling standards for both satellites are rather similar, it can be concluded from the overlap analysis that the accuracy of the SAC-C orbits is close to that of the CHAMP RSO.

In addition to CHAMP and SAC-C, the RSO for both GRACE satellites is produced since October 2004. Though, at the time being, the GRACE occultation measurements are switched off, permanent switch on is planned. Therefore the generation of the GRACE RSOs keeps going as long as resources allow. Recent accuracy assessments for both GRACE RSOs are compiled in Table 1, too. SLR RMS values are as large as those of CHAMP, but overlaps are about half as large as those of CHAMP and SAC-C. As the GPS receivers onboard the GRACE satellites deliver higher quality data, it can be concluded that the GRACE RSOs are of higher quality than the CHAMP and SAC-C RSOs.

Table 1. SAC-C RSO and GRACE RSO accuracies

	SLR RMS (cm)	Overlap Mean (cm)
SAC-C	-	5.4
GRACE A	5.2	2.8
GRACE B	4.8	2.9

4 Increasing the Accuracy of GPS and LEO Orbits

Ambiguity fixing (Mervat, 1995) for GPS observations is tested for a small sample of the GPS Post-processed Science Orbits (PSOs, 30 s ephemerides and clocks for sub-sequent gravity field processing). Table 2 summarizes the comparison of the standard and the ambiguity-fixed PSOs to the IGS final orbits for three 1.5-d arcs of May 2002. The IGS final orbits are considered as a reference because IGS claims, as in case of the IGR, that their accuracy is better than 5 cm (IGS, 2005). For further assessment, two out of all individual contributions to the combination of the IGS final orbits, the final orbits of the CODE and GFZ IGS analysis centers, are compared the same way as the PSOs to the IGS final orbits.

From Table 2 it can be conluded that ambiguity fixing improves the accuracy of the PSOs considerably. GFZ final and CODE final orbits should be as close as 2 cm to the IGS final orbits according to the IGS combination reports. However the values in Table 2 differ quite largely from this particularly for the GFZ finals. The reason being the weighting scheme applied in the combination whereas the results in Table 2 are derived from straightforward differences of all satellites being equally weighted.

Table 2. Impact of ambiguity fixing. Differences in position per axis for various orbits versus IGS final orbits

Arc	Standard PSO RMS (cm)	PSO with ambiguity fixing RMS (cm)	GFZ final RMS (cm)	CODE final RMS (cm)
2002.05.01	13.8	9.9	10.2	3.6
2002.05.03	11.4	6.9	8.5	3.2
2002.05.05	9.7	5.7	7.0	3.1
Mean	11.6	7.5	8.6	3.3

The GPS PSO (standard and with ambiguity fixing) was next used to generate CHAMP RSO type orbits for the period 2003.08.01 - 2003.08.14. Some arcs were excluded a priori because of gaps in the GPS clock solutions. Generally the CHAMP RSO is generated using the 5 minutely spaced ephemerides and clocks of the GPS RSOs. The 5-minute clocks are then being linearly interpolated to 30-second clocks. The impact of these different GPS orbits and clocks on CHAMP RSO accuracy can be seen in Table 3. The largest impact comes from proper 30-second clock solutions, case GPS PSO, for which the CHAMP SLR RMS drops drastically. The ambiguity fixed PSOs improve the CHAMP orbits additionally. Ambiguity fixing as well as improved interpolation of the 5-minute clocks of the GPS RSO will be implemented in the next future.

Table 3. Impact of GPS clocks and ambiguity fixing on CHAMP RSO type orbits measured by independent SLR residuals. CHAMP arcs where attitude and thruster data are missing, are marked by (*)

Arc	Standard GPS RSO RMS (cm)	Standard GPS PSO RMS (cm)	PSO with ambiguity fixing RMS (cm)	Number of SLR normal points
030801 10:00	3.68	2.08	2.00	167
030801 22:00	2.94	3.47	4.49	51
030802 10:00	3.81	2.46	2.54	139
030802 22:00	5.29	4.57	4.38	28
030803 10:00*	4.53	2.35	1.40	59
030803 22:00	0.13	1.10	0.04	1
030804 10:00	2.52	2.06	1.68	148
030804 22:00	2.90	2.72	3.59	45
030805 10:00	4.29	4.50	3.54	96
030805 22:00	5.11	3.17	3.47	122
030807 22:00	3.51	1.16	2.54	47
030808 10:00*	4.90	4.90	4.49	120
030808 22:00*	5.60	4.00	4.73	38
030810 10:00*	2.99	4.22	5.79	162
030810 22:00	4.94	5.67	4.33	66
030811 10:00	3.93	3.52	3.06	170
030811 22:00	3.51	3.89	2.93	81
030812 10:00	3.06	3.60	2.86	194
030812 22:00	4.19	3.05	2.25	49
030813 10:00	5.69	2.64	3.18	232
030813 22:00	6.02	3.29	3.48	52
030814 10:00	5.73	5.09	4.58	51
Global SLR RMS				
All arcs	4.24	3.48	3.45	2118
Arcs (*) excluded	4.24	3.30	3.08	1739

Another possibility for improving the LEO orbit accuracies is to use the integrated approach (Zhu et al., 2004) where all LEO and GPS orbits and the ground station coordinates are estimated in one step. Some results for a few GRACE 1.5-day arcs under different observation scenarios are given in the cited article. Here the integrated approach is applied for two months of GRACE A/B 1-day orbits and shown in Table 4. For comparison, also RMS values of SLR residuals are given for GRACE orbits produced during gravity field screening and for JPL reduced dynamic orbits. In the gravity screening runs, accelerometer data and empirical forces were used to achieve good initial orbits. For the integrated solution, solely accelerometer data were used. The independent SLR RMS for the integrated solutions is slightly larger than for the JPL solution. The difference can be deduced to gaps in the accelerometer data in the integrated solution. Therefore the integrated approach can produce LEO orbits accurate on the level of 2-3 cm.

Table 4. GRACE A and B orbit accuracies for three different solutions measured independently by 9872 SLR normal points for the period 2003.07.02-2003.08.31

Solution	RMS (cm)
Routine gravity screening (1.5d arcs, accelerometer + emp. coeff.)	5.15
Integrated (1-step) solution (1d arcs, accelerometer only)	2.92
JPL solution (reduced dynamic)	2.33

5 Summary and Conclusions

Rapid and ultra-rapid GPS, CHAMP, SAC-C and GRACE orbits generated operationally by GFZ e.g. for GPS radio occultation applications are accurate and reliable products. Recent improvements concern the optimized selection of a suitable GPS ground station network that resulted in more reliable GPS RSOs and USOs. Faster procedures for data acquisition and pre-processing led to considerable smaller latencies of the USOs. By applying ambiguity fixing and accurate GPS clock interpolation the LEO orbits can be generated on an operational basis with an anticipated accuracy of 2–3 cm versus the current 4–5 cm. Further accuracy improvements are possible by the integrated approach which, due to its large needs on computational resources, seems at this time to be of practical relevance only if it is applied offline. As demonstrated by the adoption of the SAC-C and GRACE A/B RSOs, the GFZ operational system is prepared to accomodate further future LEO missions carrying onboard GPS where fast and accurate orbits are required.

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