PDR GPS Satellite Orbits

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PDR GPS Reprocessing

One major motivation for the establishment of the International GNSS Service (IGS) on 1 January 1994 was the improvement of the orbit quality. At the beginning of the 1990ies, the accuracy of the GPS orbits was worse than 0.5 m. Starting with November 1993, the Analysis Center (AC) orbit submissions are combined by the IGS Analysis Center Coordinator to form the final IGS orbits. The RMS of the individual AC orbits w.r.t. the combined orbit has improved from about 20 cm in 1994 to less than 5 cm in 2005. The majority of the AC submissions even agree within 2 cm with the combined orbit nowadays. This improvement could only be achieved by a number of model and processing improvements regularly implemented by the ACs. On the other hand, the long-time series of operational IGS orbits are inconsistent due to these processing changes. In particular the quality and consistency of the orbits computed in the first years of the IGS with less sophisticated methods than nowadays could be significantly improved by reprocessing the raw GPS observation data with up-to-date models and processing strategies.

Therefore, Technische Universität München (TUM), Technische Universität Dresden (TUD) and GeoForschungsZentrum (GFZ) Potsdam reprocessed a global GPS tracking network of 202 stations starting with 1 January 1994 in a joint effort (PDR - Potsdam Dresden Reprocessing). The Bernese GPS Software (*Dach et al.*, 2007) and a processing scheme similar to that of the IGS AC at the Center for Orbit Determination in Europe (CODE) in Bern (*Hugentobler et al.*, 2005) have been used. A detailed description of this reprocessing is given in *Steigenberger et al.* (2006), this poster focusses on the reprocessed GPS satellite orbits (preliminary 1-day orbits and final 3-day orbits).

Formal Accuracy

An indicator for the formal accuracy of satellite orbits is given in the header of the SP3c orbit files. This so-called SP3c accuracy code n stands for a formal position accuracy of $\pm 2^n$ millimeters. The SP3c accuracy codes of the reprocessed 1-day orbits are shown in Figure 1. In 1994 and 1995 the accuracy is worse due to the sparse tracking network in these early years of the IGS (only 30 – 40 stations compared to 160 stations in 2005). This fact is also visible in the internal consistency tests that will be discussed below. Later on, the formal accuracy is in general below one centimeter. The mean SP3 accuracy code of all 1-day orbits is 3.18 (corresponding to 9.1 mm), the mean value of the final 3-day orbits is 1.60 (corresponding to 2.6 mm). However, one has to be aware that these formal accuracies are quite optimistic.

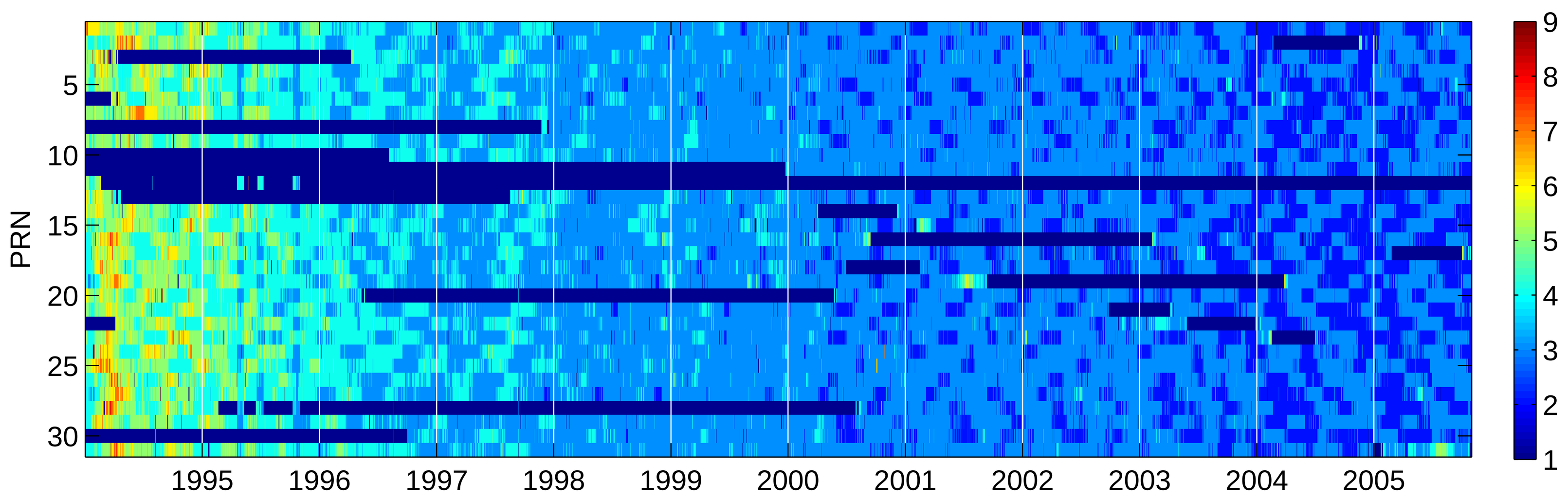

FIGURE 1: Formal accuracies of the 1-day PDR GPS satellite orbits (SP3c accuracy codes). PRNs not occupied are given in dark blue.

Internal Consistency

To quantify the internal consistency of the satellite orbits, 3-day orbit arcs were fitted through 3 consecutive 1-day orbits. The mean RMS of the 3-day arc w.r.t. the three 1-day arcs serves as a quality indicator. Time series of two individual satellites (namely SVN 17 and SVN 21) are shown in Figure 2 for the operational CODE orbits and our reprocessed PDR orbits. At the beginning, the CODE orbit fits show a periodic signal whose maxima coincide with the zero-crossings of the elevation of the Sun above the orbital plane (not shown here). After changing the constraints on the radiation pressure parameters at CODE in August 1996, this periodic signal vanishes and the orbit quality increases. However, the CODE orbit fits are still worse by a factor of about two for the time period shown in Figure 2.

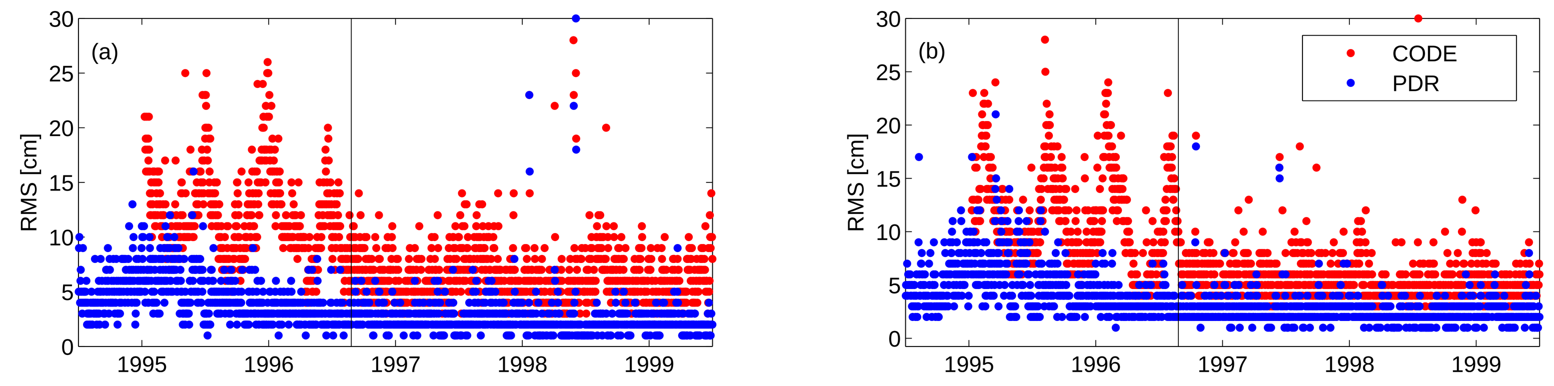

FIGURE 2: RMS values of 3-day orbit fits through 1-day operational CODE and reprocessed PDR orbits for (a) SVN 17 and (b) SVN 21. The CODE orbit fits show a periodic signal whose maxima coincide with the zero-crossings of the elevation of the Sun above the orbital plane. This signal vanishes after changing the orbit modeling at CODE in August 1996 (indicated by a vertical line).

Weekly mean orbit fit RMS values for the different satellite blocks are shown in Figure 3 for the reprocessed PDR orbits and the operational CODE orbits. The increased RMS values for the Block II satellites between 2001 and 2003 that are present for both, the CODE and the PDR orbits, are related to the aging of some of these satellites (problems with momentum wheels resulting in thruster firing for attitude control). The situation improves in mid of 2003 when the attitude control system of two of these problematic Block II satellites (SVN 15 and 17) was changed. During three short time periods in 1995, the RMS values are smaller by a factor of about two due to the temporary deactivation of anti-spoofing. The large RMS values of the Block IIR-A satellites (actually only one satellite for more than two years) in the CODE series are related to an erroneous vertical satellite antenna offset used within the IGS until November 1998.

In general, the RMS values in 1995 could be reduced by a factor of about two by reprocessing the orbits. Between 1996 and 2000, the RMS values of the CODE orbits are in general above the 5 cm level whereas the reprocessed orbits are on a level below 5 cm. A clear improvement of the CODE orbits can be seen in June 2000 when the pseudo-stochastic pulses have been changed. After switching to an improved ambiguity resolution strategy in March 2002, the internal consistency of the CODE and the reprocessed orbits is on almost the same level of 1 to 2.5 cm.

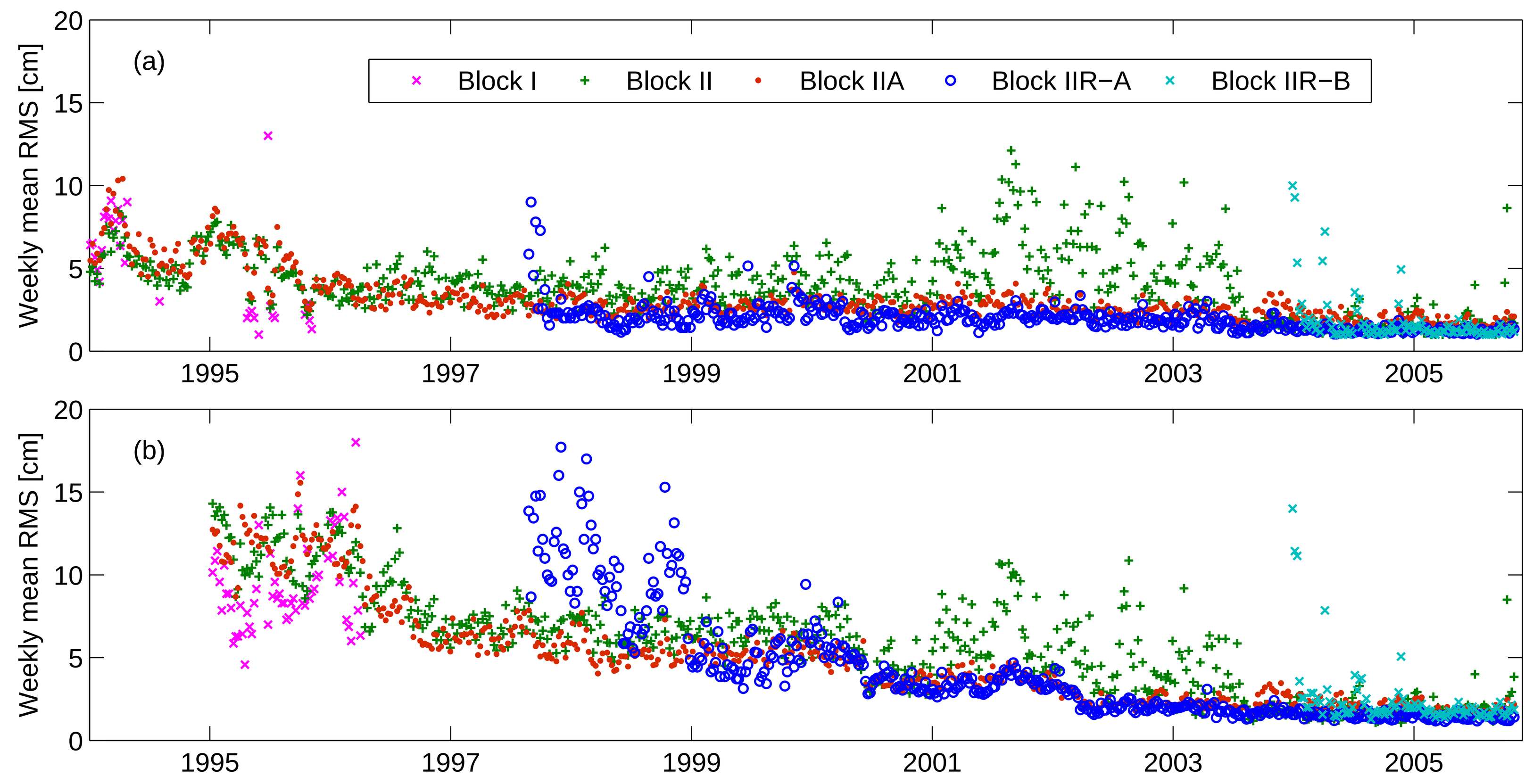

FIGURE 3: Mean weekly RMS values of 3-day orbit fits through 1-day orbits for the different types of GPS satellites: (a) PDR reprocessed orbits; (b) CODE operational orbits.

Validation with Satellite Laser Ranging

As two of the GPS satellites (SVN 35 and 36) are equipped with laser retroreflector arrays, these satellites can be tracked with Satellite Laser Ranging (SLR). Thus, the satellite orbits computed from the GPS microwave observations can be validated by an independent (optic) technique. In the following, range residuals, i.e. differences between the SLR range and the range computed from the GPS-derived orbits, will be used for comparisons. Due to the high altitude of the GPS satellites, these range residuals are approximately equivalent to the radial orbit accuracy. The SLR residual time series of the PDR final 3-day orbits of SVN 35 is shown in Figure 4.

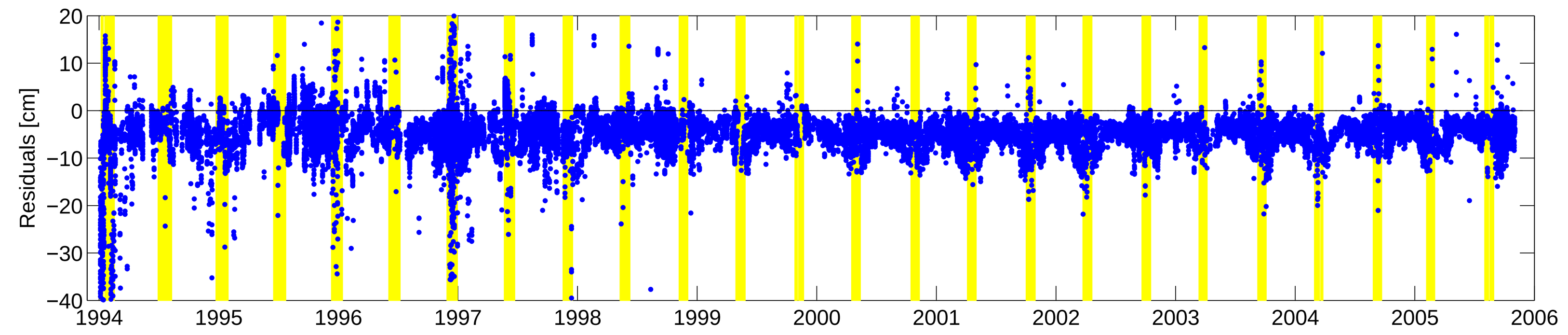

FIGURE 4: GPS-SLR residual time series for SVN 35. Eclipse periods are given in yellow.

Figure 5 shows monthly mean residuals for one year at the beginning, at the middle and at the end of the reprocessing period for SVN 35. In 1994, the mean residuals of the PDR orbits could be reduced by 27% compared to the IGS orbits and by 30% compared to the CODE orbits. In 1999, the residuals of the PDR orbits are only slightly smaller than those of the IGS orbits whereas the CODE residuals are slightly worse compared to IGS. In 2004, the residuals of the three orbit solutions are on average on almost the same level. The SLR residuals indicate that a huge improvement in the orbit quality can be achieved by completely reprocessing the orbits in the years 1994 – 1997 (only shown here for 1994). On the other hand, the orbit quality – as evaluated by SLR – can only slightly be improved after 1997.

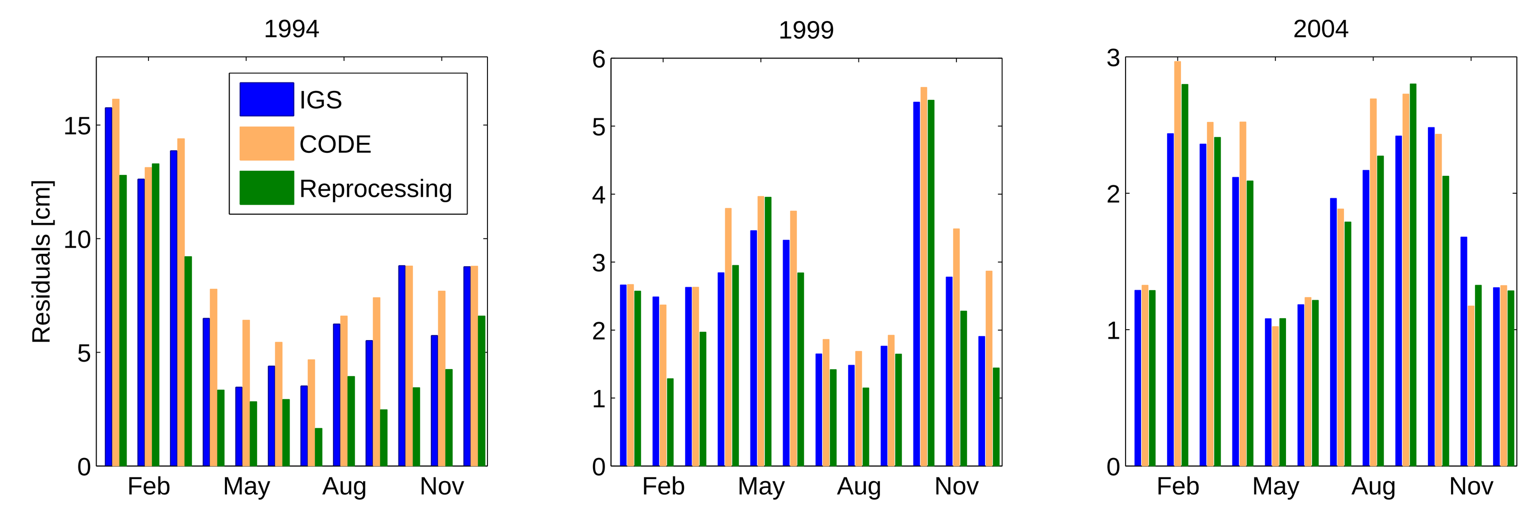

FIGURE 5: Monthly mean SLR residuals of SVN 35 for 1994, 1999 and 2004. Please note the different scale on the y-axis.

Orbit Availability

The GPS satellite orbits discussed in this poster (SP3c and internal Bernese format) and consistent Earth rotation parameters are publicly available at the Information Systems and Data Center (`http://isdc.gfz-potsdam.de/gps-pdr`) of GFZ Potsdam or at TU Dresden (`http://www.tu-dresden.de/ipg/reprocessing.html`).

References

Dach, R., U. Hugentobler, P. Fridez, and M. Meindl (Eds.) (2007), *Bernese GPS Software Version 5.0*, Astronomical Institute, University of Bern, Bern, Switzerland.

Hugentobler, U., S. Schaer, R. Dach, M. Meindl, and C. Urschl (2005), Routine processing of combined solutions for GPS and GLONASS at CODE, in *Celebrating a Decade of the International GPS Service, Workshop and Symposium 2004*, edited by M. Meindl, Astronomical Institute, University of Berne, Berne, Switzerland, published on CD-ROM.

Steigenberger, P., M. Rothacher, R. Dietrich, M. Fritsche, A. Rülke, and S. Vey (2006), Reprocessing of a global GPS network, *Journal of Geophysical Research*, *111*, B05402, doi:10.1029/2005JB003747.