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Effects of different antenna phase center models on GPS-derived reference frames

P. Steigenberger, M. Rothacher
Department of Geodesy and Remote Sensing, GeoForschungsZentrum Potsdam, Telegrafenberg A17, D-14473 Potsdam, Germany

R. Schmid, P. Steigenberger
Institut für Astronomische und Physikalische Geodäsie, Technische Universität München, D-80290 München, Germany

A. Rülke, M. Fritsche, R. Dietrich
Institut für Planetare Geodäsie, Technische Universität Dresden, D-01062 Dresden, Germany

V. Tesmer
Deutsches Geodätisches Forschungsinstitut, Alfons-Goppel-Straße 11, D-80539 München, Germany

Abstract. In GPS week 1400, the International GNSS Service (IGS) switched from a relative antenna phase center model (APCM) for receiver antennas only to an absolute model including receiver and satellite antenna corrections. At the same time the International Terrestrial Reference Frame 2005 (ITRF2005) was adopted. These changes had a significant influence on the terrestrial reference frame (TRF). In order to study the influence of different APCMs on GPS-derived TRFs, four TRF solutions have been computed from 11 years of homogeneously reprocessed GPS data. The processing strategy for the four solutions is completely identical except for the APCM applied. The following models have been used: (1) the relative model IGS01 used by the IGS till GPS week 1400, (2) the new absolute IGS model IGS05 including radome calibrations, (3) IGS05 ignoring the radome calibrations for the receiver antennas, and (4) IGS05 including azimuth-dependent satellite antenna phase center variations (PCVs). Station coordinates and velocities have been estimated simultaneously with daily pole coordinates. Consistent time series of station coordinates have been generated using the corresponding reference frames for datum definition. This paper compares the station coordinates and velocities as well as the station coordinate time series arising from the four different reference frames.

Keywords. Terrestrial reference frame, antenna phase center model, Global Positioning System

1 Introduction

A GPS observation corresponds to the distance between the electromagnetic phase centers of the transmitting and the receiving antenna. Usually these phase centers are neither fixed nor identical with the points the observations refer to: the center of mass of the satellite and a mechanically well-defined antenna reference point of the receiver antenna. The GPS APCM consists of a phase center offset (PCO) and the corresponding PCVs. The PCO is the correction for the difference between the mean electromagnetic and the mechanical reference point, the PCVs express the direction-dependence of the location of the actual electromagnetic reference point.

The relative model IGS01 has been used within the IGS since 1996. It was based on the arbitrary assumption that the PCVs of the reference antenna `AOAD/M_T` are zero. The zenith-dependent PCVs of the other antenna types were determined relative to the reference antenna (Mader, 1999). For the satellite antennas only block-specific PCOs (no PCVs) were given. This model was replaced by the absolute model IGS05 in GPS week 1400 (5 November 2006). The latter model includes zenith- and azimuth-dependent

Table 1: APCMs applied for the generation of the TRF and the time series.

APCM	Type	Receiver antenna model			Satellite antenna model	
		zen.-dep. PCVs	az.-dep. PCVs	radomes	nad.-dep. PCVs	az.-dep. PCVs
IGS01	rel.	x	-	-	-	-
IGS05	abs.	x	x	x	x	-
IGS05woR	abs.	x	x	-	x	-
IGS05azi	abs.	x	x	x	x	x

PCVs for receiver antennas and several antenna/radome combinations determined by absolute robot calibrations (Menge et al., 1998). If a robot calibration is not available for a certain antenna type, converted relative calibrations are used. For the satellite antennas, block-specific nadir-dependent PCVs and satellite-specific vertical PCOs estimated from global GPS solutions (Schmid et al., 2007) are given. The horizontal block-specific PCOs are the same as for IGS01. In addition to the nadir-dependent satellite antenna PCVs of IGS05, Schmid et al. (2005) could show that the satellite antennas also show an azimuth-dependent pattern. These different APCMs are applied in global GPS solutions in order to study their influence on the TRF and coordinate time series.

2 GPS reference frame and time series solutions

The four different APCMs applied for the generation of the TRF and the time series are listed in Table 1. All reference frame solutions are based on a complete and homogeneous reprocessing of a global GPS network (202 stations) conducted by Technische Universität München (TUM) and Technische Universität Dresden (TUD). The general processing strategy is described in Steigenberger et al. (2006). However, the results discussed in this paper are based on a more recent reprocessing including the following major modifications:

- Isobaric Mapping Function (Niell, 2000) with ECMWF (European Centre for Medium-Range Weather Forecasts) data for the mapping of the hydrostatic a priori delay

- second and third order ionospheric corrections applied according to Fritsche et al. (2005).

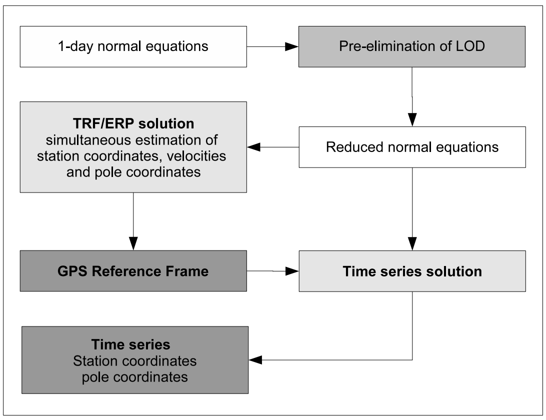

Fig. 1: Processing scheme of the TRF and time series solutions.

All solutions are completely identical except for the APCM used. They cover the time interval from 1 January 1994 till 31 December 2004. IGS01 is the relative phase center model provided by the IGS (`ftp://igscb.jpl.nasa.gov/igscb/station/general/igs_01.atx`).
IGS05 is the new IGS absolute phase center model, a combined model containing satellite antenna corrections determined by TUM and GeoForschungsZentrum Potsdam (Schmid et al., 2007). The preliminary version igs05_test (`ftp://igscb.jpl.nasa.gov/igscb/station/general/pcv_proposed/igs05_test.atx`) that was used for solution IGS05 includes calibrations for 22 antenna/radome combinations. In the more recent versions of IGS05 (`igs05_wwww.atx` with the GPS week `wwww` of the latest update) the GPS satellite antenna corrections are identical to those in `igs_test05.atx`. However, several receiver antenna and antenna/radome calibrations, recently launched GPS satellites as well as GLONASS satellites have been added in the meantime. Solution IGS05woR is identical to IGS05 except that radome calibrations were

Table 2: Offsets and rates of the translations(dX, dY, dZ), rotations (rX, rY, rZ) and the scale of solutions with different APCMs w.r.t. IGb00 obtained from a 14-parameter similarity transformation of the datum stations of the corresponding reference frames. The epoch of the offsets is 1 January 2000.

Solution	dX [mm]	dY [mm]	dZ [mm]	rX [mas]	rY [mas]	rZ [mas]	Scale [ppb]
	dX rate [mm/y]	dY rate [mm/y]	dZ rate [mm/y]	rX rate [mas/y]	rY rate [mas/y]	rZ rate [mas/y]	Scale rate [ppb/y]
IGS01	1.2 ± 0.4	6.3 ± 0.4	0.1 ± 0.4	-0.084 ± 0.032	0.026 ± 0.033	0.021 ± 0.036	0.98 ± 0.07
	0.3 ± 0.4	2.8 ± 0.4	-2.8 ± 0.4	-0.058 ± 0.032	0.023 ± 0.033	0.010 ± 0.036	0.34 ± 0.07
IGS05	-4.6 ± 0.4	9.1 ± 0.4	-5.3 ± 0.4	-0.170 ± 0.032	-0.018 ± 0.033	0.106 ± 0.035	0.20 ± 0.07
	0.4 ± 0.4	1.4 ± 0.4	-1.8 ± 0.4	-0.034 ± 0.032	0.017 ± 0.033	0.002 ± 0.035	0.12 ± 0.07
IGS05woR	-3.8 ± 0.4	9.1 ± 0.4	-4.8 ± 0.4	-0.166 ± 0.031	-0.009 ± 0.032	0.095 ± 0.034	0.20 ± 0.06
	0.5 ± 0.4	1.4 ± 0.4	-1.6 ± 0.4	-0.031 ± 0.031	0.017 ± 0.032	0.001 ± 0.034	0.12 ± 0.06
IGS05azi	-4.7 ± 0.4	8.9 ± 0.4	-5.4 ± 0.4	-0.167 ± 0.031	-0.019 ± 0.032	0.104 ± 0.034	0.26 ± 0.06
	0.3 ± 0.4	1.4 ± 0.4	-1.8 ± 0.4	-0.033 ± 0.031	0.017 ± 0.032	0.002 ± 0.034	0.12 ± 0.06

ignored. For solution IGS05azi block-specific azimuth-dependent PCVs for the satellite antennas (Schmid et al., 2005) were added.

The processing scheme to obtain the TRF and time series solutions is shown in Fig. 1. The TRF solutions are based on normal equations (NEQs) including station coordinates and Earth rotation parameters (ERPs). As satellite techniques are not able to determine UT1, the corresponding length of day (LOD) parameters are pre-eliminated in a first step. The reduced NEQs are accumulated and station coordinates as well as velocities are estimated in one single program run together with daily pole coordinates to guarantee full consistency of the TRF and the ERPs. A subset of 66 stable IGb00 (Ray et al., 2004) stations that are not affected by discontinuities during the time period considered for the TRF solutions is used for the datum definition: a no-net-rotation condition for station coordinates and velocities w.r.t. IGb00. If a particular station is affected by a discontinuity already known from an earlier reprocessing run, two independent sets of station coordinates are estimated. The velocities before and after the discontinuity are constrained to be equal except for earthquakes. The individual GPS-only TRFs are used for datum definition in the time series solutions to avoid any reference frame induced distortions of the networks.

3 Comparison of the TRF solutions

3.1 Comparison with IGb00

The transformation parameters of a 14-parameter similarity transformation (3 translations, 3 rotations and 1 scale parameter for station coordinates and velocities) for the 66 datum stations of the four TRFs w.r.t. IGb00 are given in Table 2. The transformation parameters of the three solutions with absolute APCMs are very similar whereas they significantly differ from the IGS01 values. Except for the X translation, the IGS05 solutions show smaller rates than IGS01 for all transformation parameters (although the differences of the rotation rates are not significant) indicating that the absolute APCMs can provide a more stable realization of the terrestrial reference system. The largest differences in the transformation parameters occur for the scale and its rate. The scale offset of IGS01 is almost 1 ppb and shows a rate of 0.34 ppb/y. This scale rate is introduced by changes in the satellite constellation in conjunction with erroneous vertical satellite antenna offsets of the IGS01 model (Ge et al., 2005). IGS05 and IGS05woR provide the smallest scale offset as well as the smallest scale drift. Compared to IGS01, the scale offset can be reduced by a factor of 5 and the drift by a factor of almost 3 when switching to an absolute APCM. The reduced scale offset (achieved by fixing the IGb00 scale for the estimation of the IGS05 satellite antenna PCVs and PCOs)

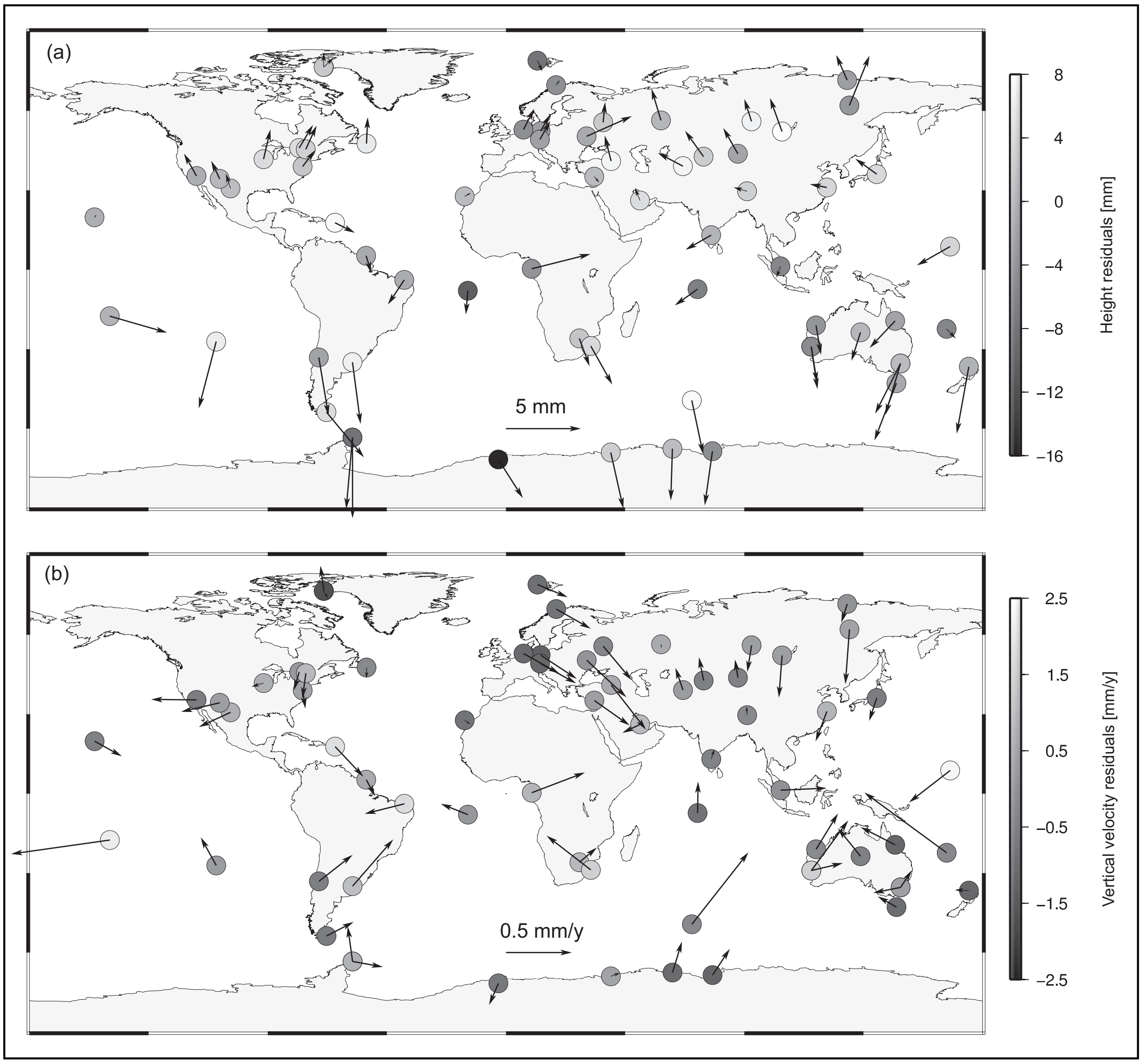

Fig. 2: Residuals of a 14-parameter similarity transformation between the solutions IGS01 and IGS05: (a) coordinate residuals; (b) velocity residuals.

and drift w.r.t. IGb00 (achieved by taking into account the satellite antenna PCVs and satellite-specific vertical satellite PCOs, see Ge et al., 2005) is the most striking advantage of the absolute APCM. The effect of considering radome calibrations on the TRF is quite small as also the number of calibrated antenna/radome combinations is small: for only 3 out of 30 datum stations equipped with a radome PCV values are available in `igs05_test.atx`. On the other hand, radome calibrations can significantly influence individual coordinate time series as shown in Sect. 4.

3.2 Inter-comparison

As the three TRFs computed with absolute APCMs only differ slightly from each other, we limit the inter-comparison to the solutions IGS01 and IGS05. The coordinate and velocity residuals after a 14-parameter similarity transformation between these two solutions are shown in Fig. 2. The horizontal residuals are below 5 mm as regards the coordinates and below 1 mm/y as regards the velocities, the vertical component ranging from −16 to +8 mm and from −2.5 mm/y to +2.5 mm/y, respectively. For some areas (e.g., Europe, East and West Coast of the United States) the coordinate and velocity

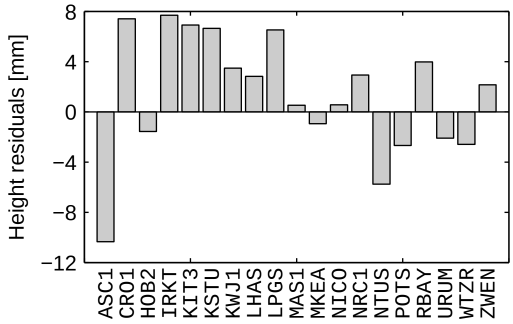

Fig. 3: Height residuals of a 14-parameter similarity transformation between the IGS01 and IGS05 TRFs for stations equipped with AOAD/M_T NONE antennas.

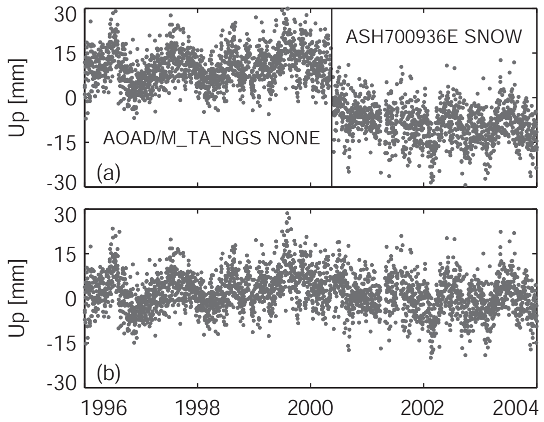

Fig. 4: Up component of Horn Point (HNPT): (a) solution IGS05woR: the antenna change from AOAD/M_TA_NGS NONE to ASH700936E SNOW resulting in a discontinuity of −15.8 mm is indicated by a vertical line; (b) solution IGS05: due to a proper calibration of the radome no discontinuity is visible.

residuals show a regional geographic correlation. For other areas (e.g., Australia) only the coordinate residuals show a geographic correlation whereas the velocity residuals seem to be quite random. The reasons for this behavior are difficult to explain as there are several important differences between IGS01 and IGS05: the consideration of satellite antenna PCVs, satellite-specific vertical PCOs, azimuth-dependent receiver antenna PCVs and radome calibrations. In addition, changes in the antenna configuration of a particular station might influence the residuals.

However, clear correlations of the residuals with the antenna type are not evident. Figure 3 shows the height residuals for all datum stations equipped with an AOAD/M_T NONE antenna for the whole time period of the TRF solution. The height residuals range from −10 to +8 mm indicating that also the station-specific environment of the antenna and not only the antenna type itself influences the station height changes.

4 Station coordinate time series

An improved modeling of the antenna phase center should also decrease the scatter of the coordinate time series. The mean RMS values of the coordinate time series of all stations with more than 1000 observation days (annual signal removed) are shown in Table 3. The RMS values of the horizontal components do not differ significantly although the most sophisticated model (IGS05azi) shows the smallest RMS values. For the vertical component the absolute APCMs show a slight RMS reduction of about 0.5 mm due to the improved modeling of the antenna phase centers.

Compared to other space-geodetic techniques, GPS coordinate time series are affected by quite a large number of discontinuities. Altogether 124 discontinuities have been accounted for in the TRF solutions, 64 of them caused by equipment changes. Some of the latter discontinuities are related to insufficient antenna calibrations, in particular if radomes are used. In the IGS01 and IGS05woR models, the effect of radomes is not accounted for whereas in IGS05 several calibrated antenna/radome pairs are included. Figure 4 shows the up component time series of Horn Point (USA) from the solutions IGS05woR and IGS05. In May 2000 the AOAD/M_TA_NGS antenna without a radome was replaced by an ASH700936E antenna with a SNOW radome. In the IGS05woR time series a clear discontinuity of −15.8 mm is visible as the result of the non-consideration of the radome. If the radome cali-

Table 3: Mean RMS of the coordinate time series for the time interval from 1 January 1996 till 31 December 2004. Stations with less than 1000 observation days have been excluded and an annual signal has been removed.

Solution	North [mm]	East [mm]	Up [mm]
IGS01	3.24	3.27	8.65
IGS05	3.12	3.22	8.12
IGS05woR	3.12	3.22	8.15
IGS05azi	3.08	3.19	8.03

bration is considered (IGS05), only a very small discontinuity of −0.5 mm (not significant) remains. This example clearly shows the necessity of a proper calibration of all antenna/radome combinations used within the IGS.

5 Conclusions

The transition from a relative to an absolute APCM has a significant influence on the TRF and the coordinate time series: horizontal coordinate changes of up to 5 mm and velocity changes of up to 1 mm/y occur. In vertical direction the changes are between −16 and +8 mm and −2.5 and +2.5 mm/y, respectively. The absolute APCM provides several advantages compared to the relative one: the drift of the transformation parameters w.r.t. IGb00 (in particular the scale drift) is significantly reduced and the RMS of the height component of the station coordinate time series decreases slightly. The availability of several radome calibrations in the absolute APCM helps to reduce the number of discontinuities in the station coordinate time series. Missing radome calibrations often induce artificial discontinuities and affect the long-term stability of the TRF. Therefore, the use of radomes should be minimized as far as possible and uncalibratable radomes (radome type `DOME`) should no longer be used.

The transition from the relative to the absolute APCM in November 2006 significantly affected the continuity of the routine IGS products. This was always the case when major model changes or processing improvements were implemented. However, the IGS contribution to the ITRF is based on these routine products of the IGS analysis centers. Therefore, also the stability and consistency of the ITRF is degraded by the changes mentioned above. For the realization of a highly-accurate reference system, completely and homogeneously reprocessed GPS solutions (like the ones discussed in this paper) that are not affected by model changes (like the APCM transition from IGS01 to IGS05) are essential. The IGS reprocessing effort will provide the basis for the computation of a reliable and consistent GPS TRF benefiting from the advantages of the absolute APCM in the near future.

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