Switching from Relative to Absolute Antenna Phase Center Variations in a Regional Network: Stability of the Coordinate Differences

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Presented at the EUREF Symposium, June 4 – 6, 2007, London, UK

Abstract

In November 2006 (more exactly GPS week 1400) the IGS analysis centers switched from using relative to absolute corrections for modeling of the GNSS antenna phase center offsets and variations. At the same time, also the EUREF analysis centers made this switch, mainly to be fully consistent with the IGS orbits. In order to evaluate the influence of the usage of relative PCV with respect to absolute PCV on the EPN site coordinates we have selected a subset of EPN stations for which absolute robot calibrations are available. We have processed this network twice using once relative and once absolute PCV and we investigated the coordinate differences between both solutions with respect to their stability in time, and the (lack of) agreement between the offsets obtained at different stations for the same antenna/radome combination.

1. Introduction

The precise point whose position is measured by a GPS receiver is generally assumed to be the electrical phase center of the GPS receiver's antenna. However, the phase center of a GPS antenna is neither a physical point nor a stable point. For any given GPS antenna, the phase centers will change with the changing direction of the signal from a satellite. Ideally, most of this phase center variation depends mainly on satellite elevation angle and azimuthal effects are smaller. GPS antenna calibrations consist of two parts: 1) an average phase center offset with respect to a physical feature of the antenna, and 2) the phase center variation (PCV) with elevation angle (and possibly azimuth). In addition, also each GPS satellite has an L-band transmitting antenna which also has a phase center which changes with elevation angle. Ideally, the offset and PCV must be used together to correctly apply the antenna calibration.

Until Nov. 2006 relative elevation–dependent PCVs were applied within the IGS and EPN. These models are based on the arbitrary assumption that the phase center variations of the reference antenna AOAD/M_T are zero. This assumption is wrong and when for distant stations, satellites are seen at relevantly different angles by the two stations, different errors on the relative PCV corrections at each of the stations is introduced so that systematic errors show up. In addition, the relative PCVs are only valid for elevation angles above 10° and also the behavior of the satellite antennas is almost ignored.
Meanwhile, for the receiver antenna, there exist absolute offsets and PCVs determined by a robotic system developed by the University of Hanover and the company Geo++, which include azimuthal values and elevations down to 0°. In addition, these absolute new PCV allowed determining absolute satellite antenna offsets and PCVs. So, a complete and consistent set of absolute PCVs for both tracking and satellite antennas is now available.

The IGS has adopted since GPS Week 1400 (Gendt, 2006) the absolute PCVs for its routine generation of precise satellite orbits and station coordinates. The EPN constitutes the European

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contribution to, and densification of, the IGS, and it strives complete consistency with the IGS standards and models: IGS orbits and Earth Rotation Parameters are used for all EPN processing and the same models are used for the antenna phase centers of the both satellites and receivers (with the exception that the EPN also accepts individual absolute calibrations). As a consequence, the EPN started using the absolute phase center models simultaneously with the IGS.
In this paper we will see how the coordinates of a regional network like to EPN are influenced by the switching from relative to absolute PCVs.

2. ITRF2005, IGS05 AND IGT05

Simultaneously with the switch from relative to absolute PCVs, the IGS started to align its orbits to the IGS05. The IGS05 is the IGS realization of the ITRF2005 (Altamimi, 2006). The GNSS contribution to the ITRF2005 was based on relative antenna phase center models and was not consistent with the new absolute PCV models used. Therefore the IGS computed a new realization, IGS05, of the ITRF2005 which can be used together with the absolute PCV models. To compute the IGS05, the IGS first determined for its reference frame stations the station–dependent coordinate differences between a solution based on absolute and relative antenna phase center models (Fig. 1 shows this difference for the EPN stations included in the IGS reference frame network). Then the ITRF2005 was corrected for this station–dependent difference and re–aligned with the ITRF2005 through a 7–parameter transformation (Ferland, 2006b) using the IGS reference frame stations. The resulting frame is the IGS05.

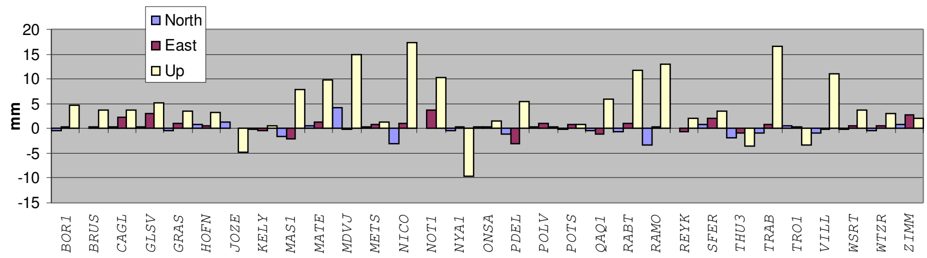

Figure 1 – Difference between station coordinates computed using relative and absolute PCVs (absolute – relative), given for the 31 EPN stations which are IGS reference frame stations (source: R. Ferland, 2006b)

Following (Ferland, 2006b), after the Helmert transformation, at the global level, the mean difference between the ITRF2005 and the IGS05 is -0.3 mm, 0.0 mm, and 0.5 mm for resp. the north, east, and up–components with standard deviations of 1.5 mm, 1.3 mm, and 10.3 mm. However, when we compute the mean over only the 31 EPN stations included in IGS05, we obtain -0.4 mm, -0.5 mm, and 4.3 mm for resp. the north, east and up-components. In addition, as can be seen in Fig. 2, there is a clear latitude dependent effect which is not correlated with the antenna/radome pairs used.

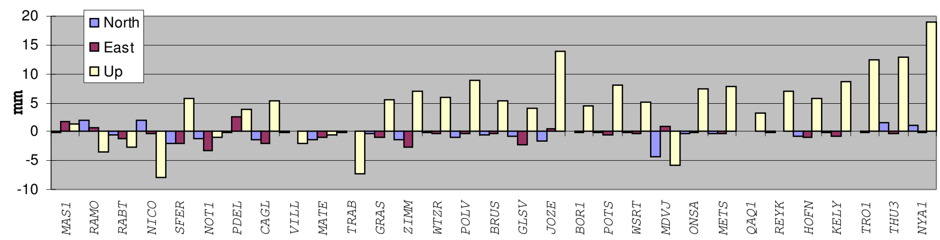

Figure 2 – Residuals of ITRF2005 minus IGS05 coordinates, given for the EPN stations which are part of the IGS reference frame stations

Next to the IGS05, the IGS also released the IGT05. The IGT05 is an extract of the ITRF2005 containing only the 130 IGS reference frame stations and it is recommended for usage when relative PCV are used. On the global level the IGS05 and the IGT05 are identical in the Helmert sense. The RMS of the Helmert residuals of the reference stations are respectively 1.5 mm, 1.2 mm, and 7.3 mm for the north, east, and up–components. On other hand, when considering only the 24 IGS reference frame stations in the European region which are equipped with antenna/radome combinations with known true absolute calibrations, the Helmert parameters between IGS05 and IGT05 are:

$$T_X = 7.1 \pm 2.7 \text{ mm}, \quad R_X = -0.22 \pm 0.08 \text{ mas}, \quad D = -5 \pm 3 \text{ ppb},$$
$$T_Y = 8.0 \pm 2.7 \text{ mm}, \quad R_Y = 0.36 \pm 0.10 \text{ mas},$$
$$T_Z = -7.8 \pm 2.6 \text{ mm}, \quad R_Z = 0.12 \pm 0.08 \text{ mas},$$

and the RMS of the residuals are respectively 1.3 mm, 1.7 mm, and 4.7 mm for north, east, and up–components. So, on the European level the IGS05 and the IGT05 are clearly different coordinate frames, which is of course expected since the IGT05 is derived from the ITRF2005.

3. Data Processing

In the beginning of GPS week 1400, 134 EPN stations (Fig. 3) were equipped with antenna/radome combinations with known true absolute calibrations (in total 23 different antenna/radome combinations, see Table 1).

Antenna	Dome	Number of Stations
AOAD/M_B	NONE	1
AOAD/M_T	NONE	15
ASH700936A_M	NONE	3
ASH700936C_M	SNOW	1
ASH700936D_M	NONE	1
ASH700936D_M	SNOW	8
ASH700936E	NONE	1
ASH700936E	SNOW	2
ASH701073.3	NONE	1
ASH701945B_M	NONE	4
ASH701945C_M	NONE	5
ASH701945C_M	SNOW	5
ASH701945E_M	NONE	2
ASH701946.2	NONE	1
JPSREGANT_DD_E	NONE	3
LEIAT504	LEIS	17
LEIAT504	NONE	6
TRM14532.00	NONE	2
TRM22020.00+GP	NONE	1
TRM29659.00	NONE	36
TRM29659.00	TCWD	11
TRM41249.00	NONE	7
TRM55971.00	NONE	1

Table 1 – Number of EPN stations for each antenna/radome combination

The relative calibrations used were based on the calibration file ftp://igscb.jpl.nasa.gov/igscb/station/general/igs_01.atx. The absolute calibrations are coming from the file ftp://igscb.jpl.nasa.gov/igscb/station/general/igs05.atx.

The observation data for GPS weeks 1400–1407 from these stations (not all stations were active) were processed with the Bernese GPS Software Version 5.0 (Dach et al., 2007) according to the standard procedure used in the ROB Local Analyses Center (see http://epncb.oma.be/ftp/center/analysis/ROB.LAC). The reference frame was realized using minimal constraints with the IGS reference frame stations which were included in the network (BOR1, BRUS, CAGL, GLSV, GRAS, HOFN, JOZE, KELY, MAS1, MATE, MDVJ, METS, NICO, NOT1, PDEL, POLV, POTS, REYK, SFER, TRAB, TRO1, VILL, WTZR, ZIMM).

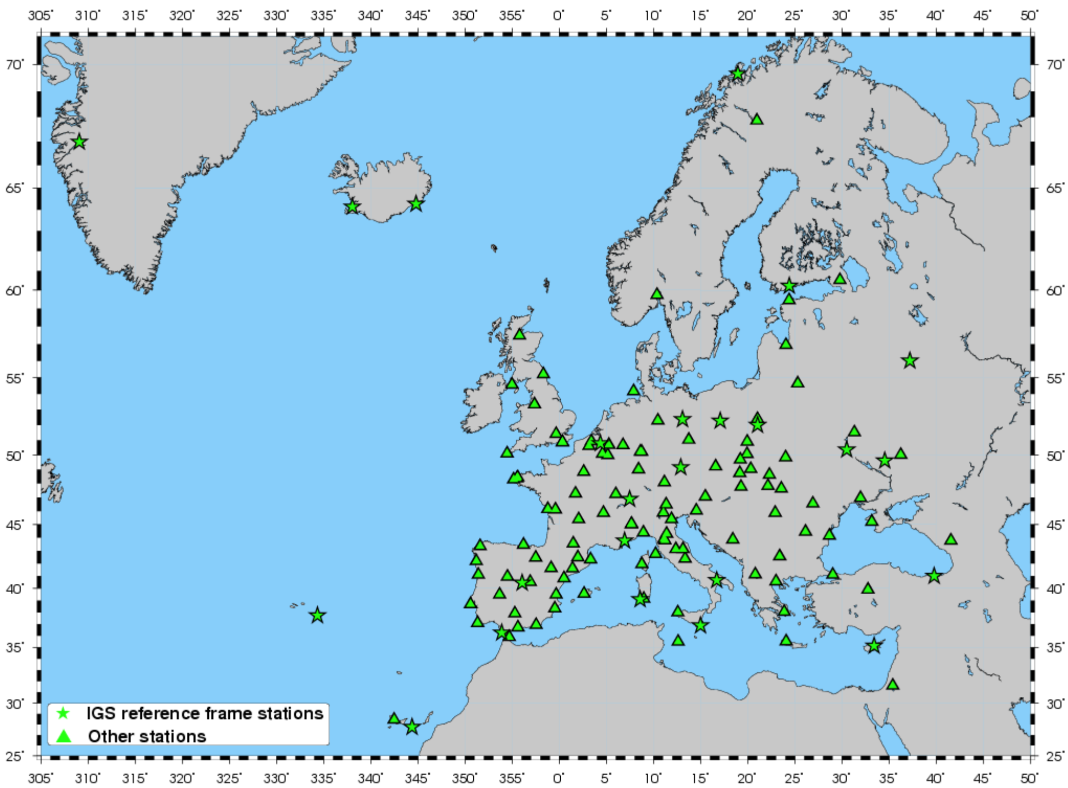

Figure 3 – EPN stations equipped with antenna/radome combinations with known true absolute PCV calibrations

The processing scheme we used in our investigation is presented in Figure 4. The data were processed twice, once using absolute (APCV) and once using relative PCV (RPCV). In the APCV run, the solution was tied to the IGS05 with minimal constraints. And in the RPCV run, two solutions were generated, one tied to the IGT05 and another to the IGS05. Then we computed the Helmert transformations between the coordinates resulting from the APCV run and the ones from the two RPCV runs. The coordinate residuals were the same in both cases. So, only the IGS05 was used for the following tests. The daily coordinates from the RPCVs were compared to the coordinates from the APCVs run using a Helmert transformation.

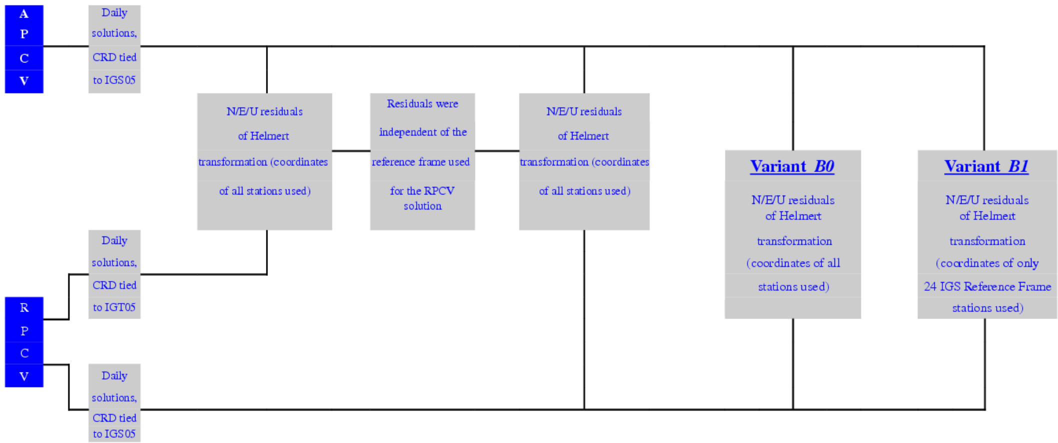

Figure 4 – Processing scheme.

4. Results

We computed two different 7–parameter Helmert transformations between the each set of daily APCV and RPCV coordinates. In the first, the Helmert parameters were computed using all stations involved in the network (variant *B0*). In the second one, only the 24 European IGS reference frame stations were used to determine the Helmert parameters (variant *B1*). Fig. 5 shows the values of daily computed scale factor between the APCV and RPCV solutions for both variants. Its mean values are 2.65±0.28 ppb (variant *B0*) and 2.90±0.42 ppb (variant *B1*) which is the size of the bias between the 2005-2006 IGS solution (obtained using RPCV) and the ITRF (Ferland, 2006a).

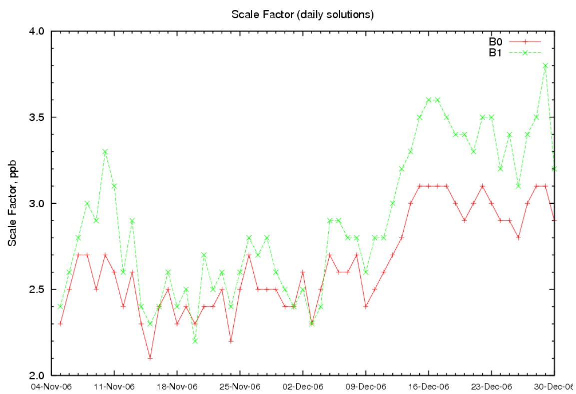

Figure 5 – Scale factor between daily solutions

The daily coordinate residuals (North/East/Height) of both Helmert transformations provide interesting information. The height component is mostly affected by the change of the PCV model. Fig. 6 shows for both variants and for the stations with the most popular antenna/radome combinations the mean of the daily height residuals together with its formal errors (1 sigma). As expected, the change in the estimated scale factor of variant *B1* with respect to variant *B0* leads to a change in the height component of the residuals. It indicates the sensibility of the estimated height differences with respect to the reference frame realization.

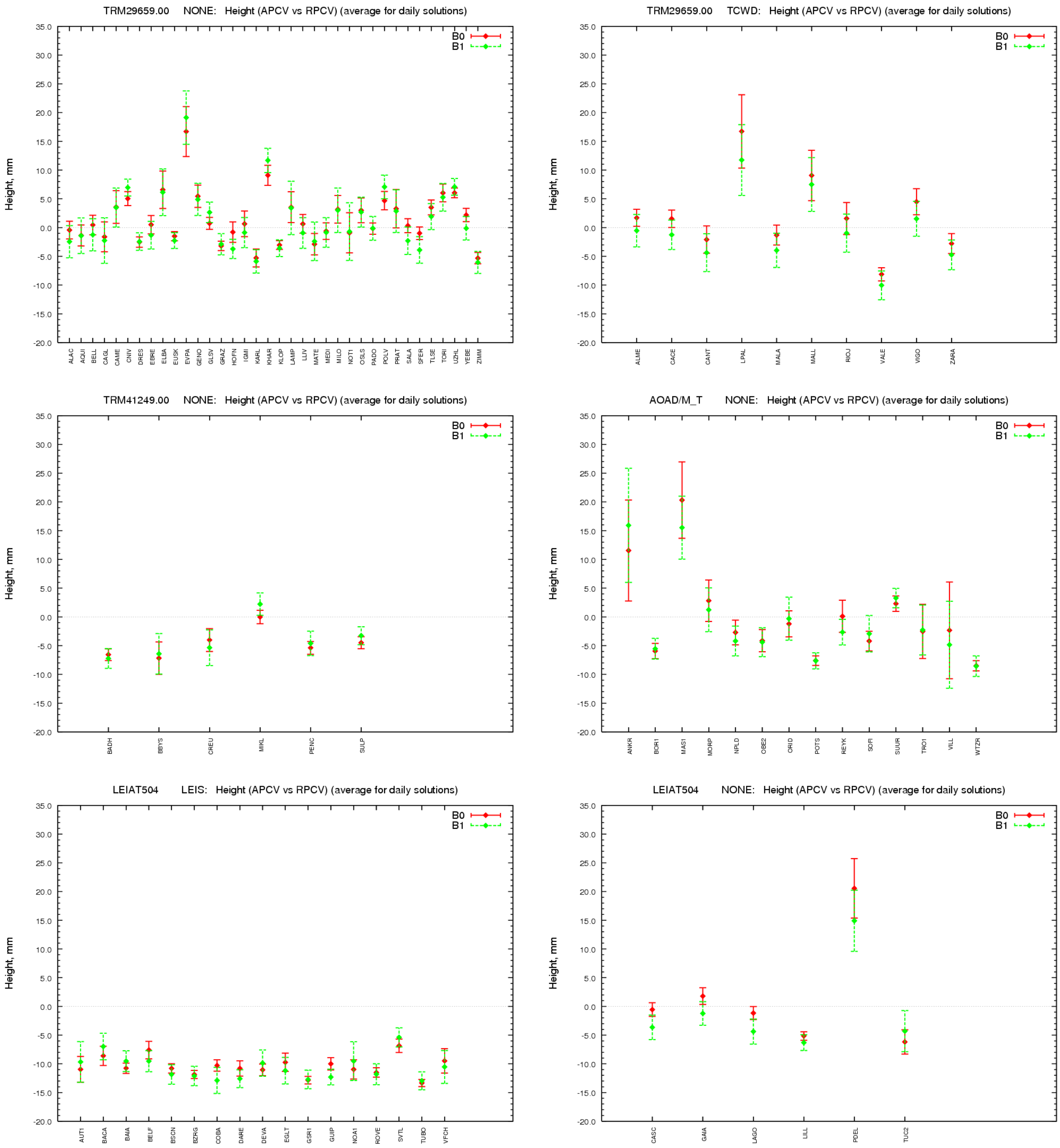

Figure 6 – Mean values of the height residuals for two different variants of Helmert parameter determination

Figures 7 and 8 show respectively the height and horizontal residuals for some antenna/radome combinations (variant *B0*). In most cases the agreement between the height residuals obtained for the different stations with the same antenna/radome combination is at the 5–10 mm level. Exceptions are the “TRM29659.00/TCWD” and “ASH700936D_M/SNOW” combinations with very different residual values between the different stations.

The stations at the eastern and western borders of our network have height residuals which are not in agreement with the results obtained for the same antenna/radome combinations at other, more central, stations (Fig. 7). Examples are:

– MAS1 with “AOAD/M_T/NONE”
– PDEL with “LEIAT504/NONE”

- LPAL with “TRM29659.00/TCWD”
- MDVJ with “JPSREGANT_DD_E/NONE”
- KELY with “ASH701945C_M/NONE”,
- ZECK, TRAB, and DRAG with “ASH700936D_M/SNOW”

The same type of outlier is also found in the horizontal components of stations at the northern and southern borders of the network (Fig 8):

- TRO1, REYK, MAS1 with “AOAD/M_T/NONE”
- LPAL with “TRM29659.00/TCWD”
- KELY with “ASH701945C_M/NONE”
- PDEL with “LEIAT504/NONE”

We suspect that the fact that the border stations are producing APCV – RPCV differences which are not in agreement with the behavior of the same antenna/radome pairs at other stations is caused by our reduced ability to fix the reference frame for these border stations. In order to confirm this hypothesis, we will add some non–EPN stations surrounding our actual network to our network in our future processing to artificially change the status of the current border stations to non-border.

Table 2 shows comparison of the mean values of APCV – RPCV differences based on weekly solutions for both variants (*B0* and *B1*) with the ones presented in (Ferland, 2006b). The agreement between our values and the ones from (Ferland, 2006b) is poor. We intend to process a global network in order to find the origin of these differences.

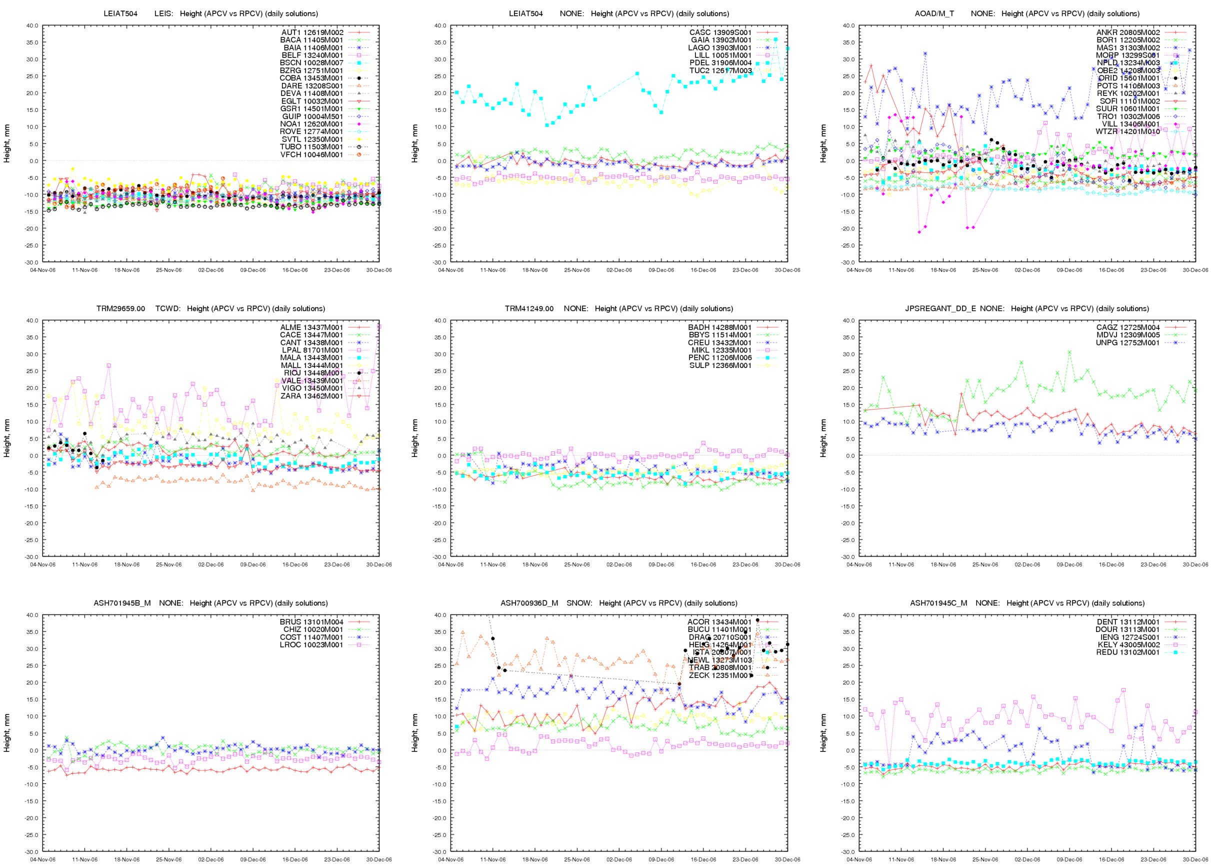

Figure 7 – Height residuals between solutions with absolute and relative PCVs

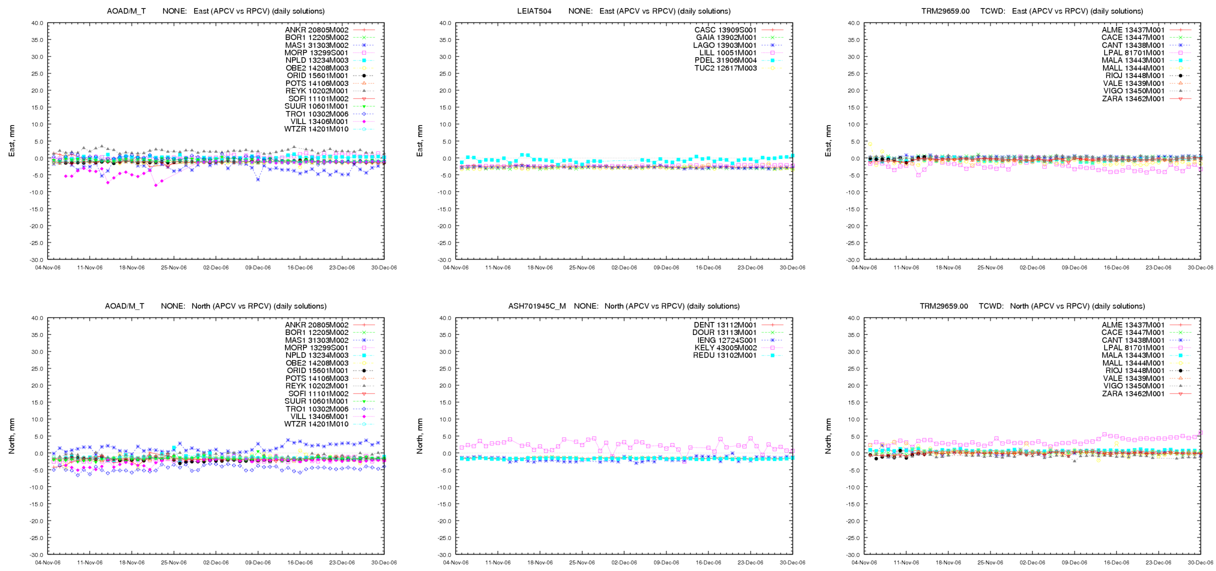

Figure 8 – Horizontal residuals between solutions with absolute and relative PCVs

Antenna	Dome	Station	Variant *B0*			Variant *B1*			(Ferland, 2006b)		
			ΔN, mm	ΔE, mm	ΔH, mm	ΔN, mm	ΔE, mm	ΔH, mm	ΔN, mm	ΔE, mm	ΔH, mm
AOAD/M_B	NONE	METS	-1.86	-1.00	-3.10	-1.09	-1.16	-2.76	0.4	0.8	1.2
AOAD/M_T	NONE	BOR1	-1.62	-1.14	-6.15	-0.57	-1.29	-6.34	-0.4	0.4	4.6
		MAS1	1.35	-2.60	19.83	1.30	-2.36	15.11	-1.6	-2.1	7.9
		POTS	-1.92	-0.94	-7.68	-0.88	-1.09	-8.25	-0.2	0.8	0.9
		REYK	-1.06	1.94	0.93	0.04	1.46	-1.86	0.1	-0.7	2.1
		TRO1	-4.47	-0.51	-2.51	-3.99	-0.35	-2.72	0.5	0.4	-3.3
		VILL	-3.04	-2.29	1.45	-2.22	-2.33	-1.21	-0.8	-0.2	11.1
		WTZR	-1.46	-1.01	-8.49	-0.34	-1.16	-9.10	-0.3	0.5	3.1
ASH700936D_M	SNOW	TRAB	2.66	-1.02	30.54	4.38	-1.20	31.34	-0.8	0.9	16.6
ASH701945B_M	NONE	BRUS	-1.59	-0.65	-5.78	-0.60	-0.82	-7.20	0.0	0.3	3.6
ASH701945C_M	NONE	KELY	1.77	4.85	8.79	3.09	3.65	5.01	-0.2	-0.5	0.6
ASH701945E_M	NONE	GRAS	-1.54	-1.14	-7.29	-0.43	-1.17	-8.62	-0.5	1.1	3.4
JPSREGANT_DD_E	NONE	MDVJ	3.06	-2.72	17.60	3.95	-3.10	19.06	4.1	-0.2	14.9
LEIAT504	NONE	PDEL	-0.80	-0.66	19.41	-0.74	-1.36	14.16	-1.2	-3.2	5.3
TRM14532.00	NONE	JOZE	-1.65	-0.11	-12.45	-0.55	-0.29	-12.27	1.2	0.0	-4.9
TRM29659.00	NONE	CAGL	-0.04	2.00	-1.91	1.14	2.17	-2.93	0.3	2.2	3.8
		GLSV	-0.17	1.12	0.51	1.04	0.82	1.61	0.2	3.0	5.1
		HOFN	-1.25	4.17	0.40	-0.12	3.60	-2.30	0.8	0.5	3.3
		MATE	-0.56	2.09	-3.38	0.85	2.15	-3.64	0.6	1.3	9.7
		NOT1	-0.25	2.12	-1.29	1.16	2.36	-1.77	0.1	3.7	10.2
		POLV	0.35	0.84	4.46	1.64	0.47	5.94	0.3	1.1	0.4
		SFER	0.93	1.71	-0.91	1.64	1.75	-4.05	0.8	1.9	3.4
		ZIMM	-0.54	1.96	-5.09	0.51	1.86	-6.32	0.7	2.8	2.0

Table 2 – Comparison of the mean values of APCV – RPCV differences

5. Conclusion

We have processed a subnetwork of the EPN consisting of the 134 EPN stations which have true absolute calibrations using both absolute (APCV) and relative (RPCV) antenna calibrations and compared the results using a 7-parameter Helmert transformation. In most cases the agreement between the height residuals we obtained for the different stations with the same antenna/radome combination is at the 5–10 mm level. However, we noticed that the height residuals for the stations at the eastern and western borders of our network and the horizontal residuals for the stations at the northern and southern borders of the network are different from other stations with the same antenna/radome combinations. This is a side-effect from the Helmert transformation. Because of this reason, it is more difficult to reliably estimate the influence of the switch from relative to absolute calibrations for these stations. We also noticed that changing the set of stations used to determine the Helmert parameters leads to significant changes in the height residuals, between 1 and 3 mm (about 5 mm for the border stations). Consequently, the question about what stations should be used for computing the coordinate residuals is still open. In addition, when comparing our APCV-RPCV differences with the results obtained by the IGS for a global network, we see a poor agreement. This indicates even more the sensibility of the obtained coordinate differences on the network used in the processing and the Helmert transformation. We intend to study this problem more in detail in the future.

Acknowledgements: *The research of O. Khoda is supported by the Belgian Science Policy.*

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