The importance of correct antenna calibration models for the EUREF Permanent Network

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Abstract

Station coordinates and velocities are derived today with a precision of a few millimetres. Nevertheless, only a limited number of accurate correction models for antennas used within the IGS is available. Over the last decade only relative calibration models have been applied for elevation dependent phase centre variations (PCV). Absolute calibrations of the GPS antennas have shown that the so far used relative correction models differ significantly from the absolute calibration models. The introduction of these new models is only possible in connection with new calibration models for the GPS satellite antennas to avoid an artificial scale factor.

Beside the type of calibration model, absolute or relative, also the question of correction models that include the dome is of importance. Up to now calibration models for antennas with dome have not been applied for the data processing within the IGS and EUREF. Therefore, systematic effects are introduced, mostly in the height component, at sites with domes.

Introduction

In the old days of GPS campaigns people were aware that each antenna type has its own characteristics and leads to different systematic errors. Since calibration methods were not well developed at that times survey campaigns for highest precision were carried out with identical antenna and receiver types. The mixing of receiver types soon became less crucial but the mixing of antenna types remained as a serious problem. SCHUPLER and CLARK (1994) soon developed a calibration method in an anechoic chamber. This calibration was used to estimate the offsets of the phase centres for each frequency (L1 and L2) in relation to an physical point of the antenna and also direction dependent phase center variations (PCV). But the method was rather complicated and not applicable for larger sets of antennas. The dominant antenna type used in the IGS network was the Alan Osborne AOAD/M_T. This antenna served as a reference for the calibration of other antenna types in a relative mode. For the AOAD/M_T only offsets in the height component were assumed for each frequency and no direction dependent PCV. A database of relative calibrated antenna types has been generated by MADER (1999) with free access to everyone. The database is updated regularly and offers a large variety of different antenna types. Even the effect of antenna domes has been considered. The drawback of relative calibrations is that the corrections are dependent on a reference antenna and the estimation of PCV at low elevations is not possible due to the appearance of much more noise and stronger multipath signals in the observation data at these elevations. Also the environment used for the antenna calibration is never completely free of multipath, which after all has an impact on the calibration results. Last but not least the satellite constellation at the location of calibration might not cover evenly the hemisphere of the antenna. At northern latitudes (or southern latitudes) the GPS constellation leads to the so called "polar hole" that hampers the complete coverage of the antenna. This can be improved by rotating the antenna, but the multipath problem still remains.

In 1996 (WÜBBENA et al., 1996) a new approach for the absolute calibration of GPS antennas has been presented by the Institut für Erdmessung (University of Hannover) and the company GEO++. Over the next years this approach has been developed into an automatic real-time calibration method for GPS antennas using a robot (WÜBBENA et al., 2000). This new method allows the estimation of the PCV in a multipath-free-environment and can estimate the PCV down to an elevation of zero degrees. The precise robot calibration allows not only the estimation of the elevation dependent but also the azimuth dependent PCV. Type specific corrections are available from a database, but the access is not free.

The calibration of GPS antennas in anechoic chambers has also been revived. Görres (GÖRRES et al. 2006) estimated independently the absolute PCV of GPS antennas in an anechoic chamber. The results of this calibration are consistent with the robot calibration. Therefore the results of both methods are verified.

Although achievements concerning the absolute calibration of GPS antennas have been made in the past years, relative calibration models are still in use in the global reference system of the International GNNS Service (IGS) and the regional reference system of EUREF. Due to a scale factor between coordinate sets computed with relative models and absolute models absolute PCV are still not introduced. A solution for the scale problem has been presented by SCHMID and ROTHACHER (2003). They have estimated elevation-dependent satellite antenna phase center variations based on absolute PCV for the GPS ground antennas. Applying these corrections for the GPS satellite antennas compensates the scale problem.

The achievements of the past years will undoubtedly lead to the introduction of absolute PCV for the ground and satellite antennas. This conversion from relative to absolute calibration models will have certainly an impact on the EUREF reference system. It is not only the systematic error caused by the conversion to absolute PCV, but also the

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introduction of correction models for antennas with dome will leave a significant trace. This paper will focus this issue and will show its impact on the sub-network of the BEK.

Computations

In *IGS-Mail 5149* (2005) a new file with absolute antenna models named *igs_test05.atx* was announced and made available for testing. The file includes ten absolutely calibrated receiver antennas, which have been calibrated with the robot by GEO++, and twelve calibrations by the NGS, which are based on relative calibrations but have been converted to absolute PCV with the AOAD/M_T absolute PCV. The satellite antenna z-offsets (satellite-specific) and patterns (block-specific) have been estimated by the Technical University of Munich (TUM) and Geo-ForschungsZentrum Potsdam (GFZ) by re-analysing 11 years of data. For this computations absolute PCV for the receiver antennas have been used. The file *igs_test05.atx* contains the mean values for the z-offsets and PCV for the satellites computed from the estimates of the two groups. The scale of the reference frame has been maintained by fixing the network solution to the IGb00.

In order to estimate the impact of the conversion from relative to absolute calibrated antennas two computations with identical data had to be carried out. In a first step coordinates of the BEK sub-network, which is part of the EUREF Permanent Network (EPN) and consists of approximately 70 stations, have been estimated using the standard set-up. Meaning that relative calibrations for the antennas were used and the impact of the dome on the antenna will not be be considered. The relative calibration values were taken from the file *igs_01.pcv* as it is still in use by the IGS and EUREF. The data of GPS week 1317 have been processed with BERNESE 5.0 using the script RNX2SNX with small modifications. The daily solution have been computed applying a minimum constraint condition for the translation and the rotation of the network based on the stations Matera (MATE), Nicosia (NICO), Villafranca (VILL) and Wettzell (WTZR). These stations are equipped with an antenna of the type AOAD/M_T. These daily solutions have then been combined to a weekly solution based on the normal equations.

The second computation is based on absolute PCV for the same network. Again BERNESE 5.0 with the script RNX2SNX has been applied on the same data. The file *igs_test05.atx* with small modifications has been used to estimate first the daily coordinates and finally the weekly solution. The modifications were due to the fact that the GEO++ database contained more type specific calibrations than the file *igs_test05.atx*. Therefore, the calibrations for the antennas ASH701945E_M and the TRM29659.00 with the *Trimble conical weather dome* (TCWD) were modified by values from GEO++. Especially the later antenna type is used in many cases and the impact of the dome is rather large. It should also be remarked that as well as the file *igs_05test.atx* and the database at GEO++ do not contain all antenna types used in this sub-network. For example the calibration values for the ASH701945C_M with the UN-AVCO dome (UNAV), the ASH701945E_M with the spherical dome developed for the *Southern California Integrated GPS Network* (SCIS) and the ASH701945C_M with a dome developed by the colleagues in Graz (GRAZ) are still missing in both data sets.

To be able to see the impact between the two datasets the difference (absolute – relative) between the two network solutions are shown in figure 1 for the horizontal and in figure 2 for the vertical components.

The differences in the horizontal components are rather small. The largest horizontal displacement can be seen for the station TGRC in Southern Italy, where a LEIAT303 antenna is used. In all other parts of the network the horizontal displacement exceeds seldom 3 mm. It can also be seen that identical antenna types show the same displacement. This especially true for the TRM29659.00 antenna, which is densely distributed close to the Alps. Figure 2 shows a different pattern. One can clearly see that the impact on the vertical components is much larger as on the horizontal components. In many places the difference exceeds 10 mm and at some locations even 15 mm. As before with the horizontal components also certain patterns that are related to specific antenna types are visible. At the east coast of the Iberian Peninsula and on the island of Majorca a number of TRM29659.00 antennas with the *Trimble conical weather dome* (TCWD) are installed. Almost all of them show the same size of vertical displacement. Similar patterns of other antenna types can be seen throughout the figure.

If one only considers the impact of the conversion from relative to absolute PCV one should look at those sites where an AOAD/M_T antenna is installed without a dome. At many of these sites the horizontal displacements are negligible. For the vertical component this is not quite true, but still the vertical displacement is a lot smaller at these sites compared to others.

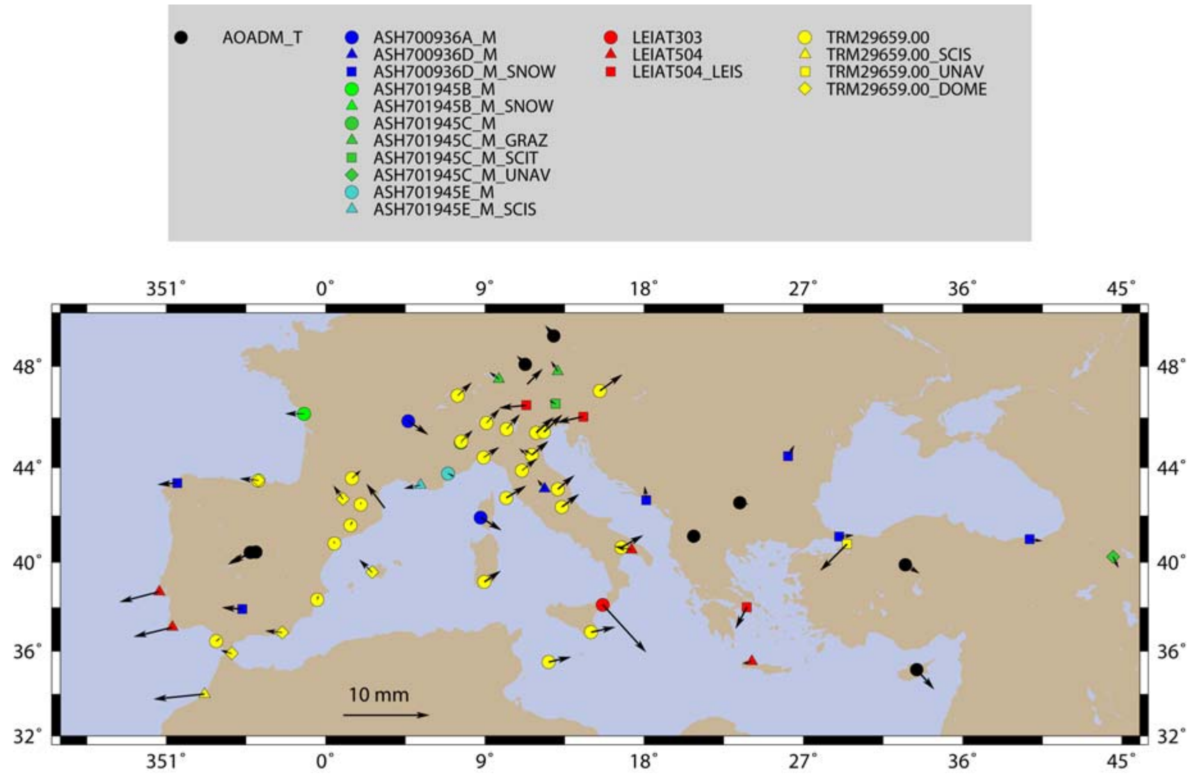

Figure 1: Differences in the horizontal components caused by the transition form relative to absolute PCV.

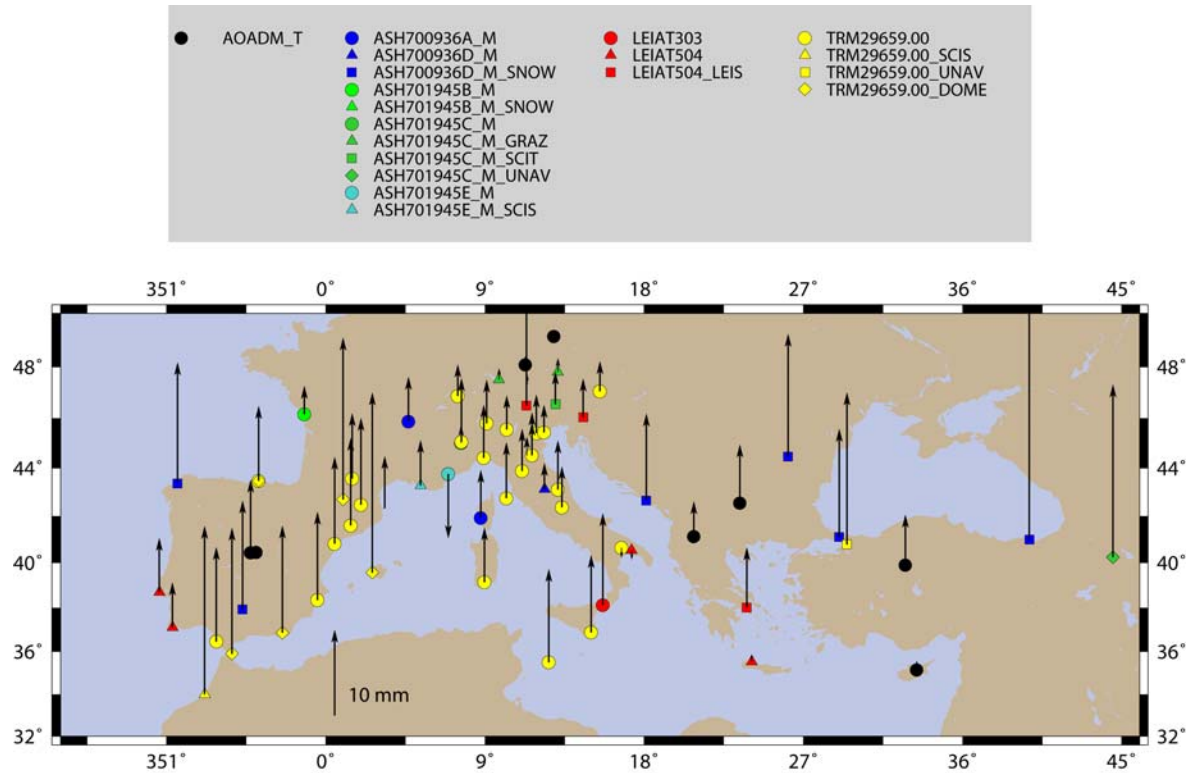

Figure 2: Differences in the vertical components caused by the transition form relative to absolute PCV.

Tabelle 1: Systematic position changes due to the transition from relative to absolute PVC for selected antennas

Antenna Type/ Samples	East	North	Height
		mm	
AOAD/M_T / 8	-0.7 ± 1.9	-0.6 ± 1.2	3.6 ± 3.1
LEIAT504 / 5	-3.1 ± 1.5	-1.2 ± 1.6	2.8 ± 3.5
LEIAT504__LEIS / 3	-2.3 ± 1.2	-0.7 ± 1.2	8.3 ± 5.1
TRM29659.00 / 24	1.4 ± 1.1	1.1 ± 0.6	6.5 ± 3.1
TRM29659.00__TCWD / 6	-1.9 ± 0.8	0.7 ± 0.6	15.5 ± 4.5

Table 1 shows the average size of displacements for some antenna types. The standard deviation of these displacements are rather large compared to the signal. This indicates that you cannot apply only correction values for the coordinates related to one antenna type, but that one also has to consider other influences. Especially the geometry of the satellite sky distribution has a significant impact on the displacement of the antenna.

Zero Baseline simulation

The impact of the satellite sky distribution will be demonstrated in a zero-baseline simulation for three sites: the station NYA1 on Spitzbergen in the North of the EPN, the station MAS1 on Gran Canaria in the South and WTZR in Germany at mid-latitudes. The sites were selected according to their position in the EPN network. For the zero baseline simulation two sets of observations from one site are processed. Both data sets are identical. The first data set is corrected with relative PCV (*igs_01.pcv*) while the second data set is corrected for absolute PCV (igs_test05.atx). Processing the two files will give a baseline that shows only the impact of the transition from relative PCV to absolute PCV for this site. The simulation has been carried out for 6 different antenna types applying relative PCV and absolute PCV, where the last one contains also corrections that have an azimuthal dependency.

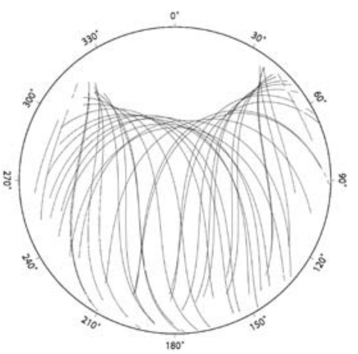

Figure 3a

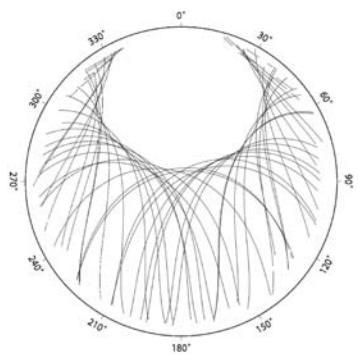

Figure 3b

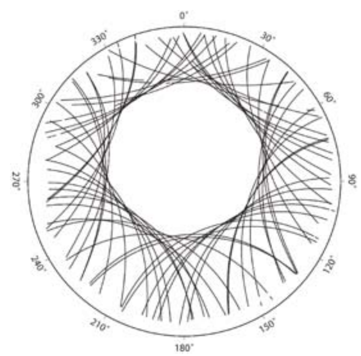

Figure 3c

Figure 3 shows the satellite sky distribution for these 3 sites and table 2 gives the displacements for some antenna types used in this simulation. The satellite paths for all stations differ significantly from each other: The station MAS1 shows a rather small polar hole, which is caused by the inclination of the satellite orbits, at lower elevations in the north. This is quite natural taking the more southern position of the site into account. WTZR is located in the centre of Europe and the polar hole is much more pronounced as on MAS1. Compared to MAS1 there are less satellite paths covering the zenith of the hemisphere of this site. The last station NYA1, which is located at high northern latitudes shows a much different picture. The polar hole in the satellite sky distribution is located directly in the zenith of the site. The highest elevation of the satellites is about 60°. On the other hand NYA1 shows satellite paths in all directions, as this is not the case for the other two sites. Table 2 shows the impact of the satellite sky distribution on the position of the antenna due to the transition from relative to absolute PCV.

For the first two sites MAS1 and WTZR the impact on the position is quite similar. The difference of the impact on these two sites seldom exceeds one millimetre. This situation changes for the station NYA1. Here the largest changes can be seen for the TRM29659.00 antenna with the TCWD-dome in the height component. The change is about 5 mm compared to the other two sites. For the horizontal component the changes are similar to the first two stations with the exception for the two Trimble antennas (TRM29659.00 and TRM29659.00 with TCWD-dome).

Tabelle 2: The impact of the transition from relative to absolute PCV on a zero-baseline.

Type	DOME	MAS1			WTZR			NYA1		
		North	East	Height	North	East	Height	North	East	Height
		mm								
TRM29659.00	-	2.4	4.4	0.2	2.1	4.3	-1.0	2.9	4.2	-1.1
TRM29659.00	TCWD	1.5	-0.4	-15.9	1.1	-0.4	-15.1	2.3	-0.6	-19.7
LEIAT504	-	1.4	1.4	-5.7	1.4	1.5	-6.1	1.6	1.5	-6.2
LEIAT504	LEIS	-1.3	0.6	-2.0	-1.3	0.6	-1.9	-0.9	0.7	-3.3
ASH700936D_M	-	1.1	-0.4	-2.2	0.9	-0.4	-2.9	1.4	-0.4	-2.0
ASH700936D_M	SNOW	1.2	-0.1	-0.5	1.3	-0.2	-0.2	1.4	-0.1	-3.2

The impact of the transition in regional networks

The zero baseline simulation only shows the influence of the different antenna calibration models in local networks, which do not exceed a few kilometres. The situation is different in regional networks. In regional networks one has to apply tropospheric corrections, which can differ significantly between sites with a spacing of a few hundred or a few thousand kilometres. Uncorrected PCV lead to errors in the tropospheric parameter estimation and will amplify the change in the height component drastically. One also has to take into account that the satellite geometry of the processed data is now a function of the two sites that form the baseline. Only those satellites that can be seen from both sites at the same time contribute to the analysis of the baseline. This will be demonstrated with the analysis of the data from the station LROC (La Rochelle, France), WTZR, MAS1 and NYA1. Baselines are computed between LROC, where a AOAD/M_T antenna is installed, and the other three sites. As before, the processing is carried out with the two different antenna calibration models. The results are shown in table 3.

Tabelle 3: The impact of the transition from rel. to abs. PCV in a regional network.

Type	DOME	MAS1			WTZR			NYA1		
		North	East	Height	North	East	Height	North	East	Height
		mm								
TRM29659.00	TCWD	0.5	-4.1	-1.4	-0.5	-4.0	-12.8	-1.1	-4.0	-33.8
LEIAT504	LEIS	-2.2	-0.7	6.1	-2.9	1.0	7.5	-4.0	-1.2	3.4
ASH700936D_M	SNOW	0.9	0.5	16.5	0.2	0.5	12.1	-0.9	0.7	4.9

This time the differences vary much for than in the zero-baseline simulation. It can also be seen that each antenna type shows its own characteristics. The smallest changes appear in general for the LEIAT504 antenna in connection with the Leica spherical dome (LEIS). This does not mean that it is a better antenna but rather that relative and absolute calibration models agree to a certain extend better. Still, even this antenna shows a change in height of about more than 7 mm between LROC and WTZR, which is not satisfactory. Generally the changes in height are the most dominant ones. The largest horizontal displacement can be seen for the TRM29659.00 antenna with the TCWD-dome and amounts to 4 mm for the east component. It also appears that the variation in the horizontal component do not vary as much as for the height component depending on the different geometrical conditions. The changes in the height component are certainly larger. Especially the TCWD-dome shows significant changes depending on the geometry. The transition from relative PCV to absolute PCV, considering also the dome, causes for the station NYA1 a systematic height error of 34 mm. For WTZR the error is still -13 mm while for MAS1 the impact is only -1.4 mm. One has to keep in mind that these are all choke ring antennas build in a very similar way and contain in principle the same electronic elements. The position changes in table 3 are mainly caused by the domes mounted on the antennas. They change the reception behaviour of the antenna, which consequently causes the change of position.

Figure 4 shows the contribution of some domes to the PCV of a specific antenna with dome. This has been computed by subtraction the elevation dependent PCV of one antenna type without dome from the PCV of an antenna of the same type with dome. The different offsets of the antennas were taken into account to estimate this differences. Figure 4a shows clearly that the TCDW-Dome shows much more variation than the other two domes. This is reflected in table 3 because here one can see the largest variations due to different satellite distributions. In figure 4b one can see the impact of the LEIS-dome on the antenna. It shows less variation in the elevation and therefore also less variation in position. The Ashtech SNOW-dome shows again larger variations compared to the LEIS-dome, which also can be seen in the position changes of table 3. All domes examined do not show a perfect behaviour. The perfect dome for positioning would have the same correction value for the complete hemisphere. The signal delay caused by such a dome would be attributed to the clock error of the receiver and would not contribute to the coordinate estimation. Nevertheless, it will have an impact on time transfer computations.

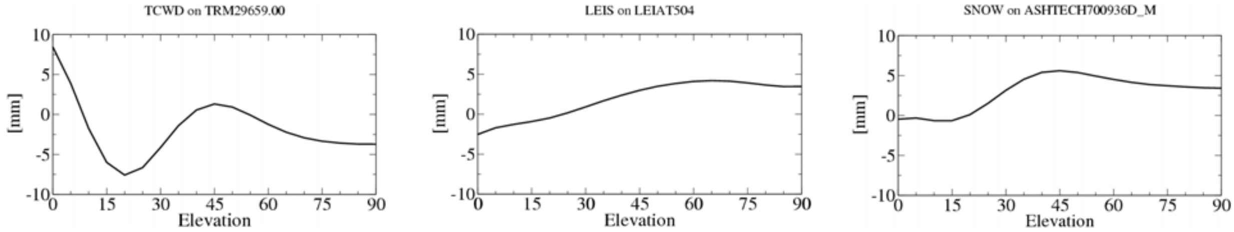

Figure 4: The impact of different dome on certain antenna types: TCWD-Dome (a), LEIS-Dome (b) and SNOW-Dome(c).

Conclusions:

The impact of the conversion to absolute PCV will be significant for the EPN. Maximum changes in height of about 30 mm can be expected at some sites. The main cause for these changes is due to the use of PCV for specific antenna domes. Nevertheless, this step is necessary in order to be consistent with the real-time networks of many National Mapping Agencies like SAPOS, where absolute PCV are already in use in some countries. Since EUREF is supposed to serve as a European reference system this steps has to be taken to provide consistent coordinates that will be accepted by the National Mapping Agencies. This step is also absolutely necessary for the development of a European Combined Geodetic Network (ECGN), where different surveying techniques like gravimetry, levelling and space techniques are merged. Only coordinates that reflect the physics can be used in a combination with other geodetic techniques. The remaining question concerns the implementation of the absolute PCV. Hopefully as soon as possible.

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