From Relative to Absolute Antenna Phase Center Calibration: The effect on the SINEX products

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Abstract

Within the IGS, all the receiver antenna types being used were calibrated in a relative sense with respect to the Dorne Margolin (AOAD/M_T) model. There are some shortcomings with this approach, such as: deficiencies for long baselines, introduction of a scale bias, satellite absolute phase centers cannot be accounted for properly. To resolve those problems, it was proposed at the last workshop to use instead absolute antenna phase center calibrations. They can be determined either from anechoic chamber results, robotic calibrations in the field, or deduced from relative calibrations. A test campaign was started last year, with participating ACs, to produce weekly station coordinates solutions using absolute phase center antennas calibrations. Those solutions were produced in parallel with the official IGS weekly station coordinates products. These weekly solutions were compared and analyzed. When absolute phase centers are officially implemented, there will be a discontinuity at all stations. This may have a significant effect on the reference frame realization, the apparent geocenter and the ERP's.

Introduction

When taking measurements with a GPS receiver for centimeter level applications, it is generally necessary to take into account the antenna phase center offsets. The precise position of the measurements within a receiver's antenna from each satellite is necessary to properly reduce the observations to a physical reference. For precise measurements, this was shown to be dependant mainly on the direction of the signal source (azimuth and orientation) as well as the frequency of the signal (L1, L2). If we disregard external effects, antennas of a given type were also shown to have similar characteristics, while antennas of different types often have systematic differences. Some calibrations include the effect of radomes. Since the early days of the IGS, the practice has been to calibrate antennas with respect to the Dorne Margolin antennas (AOAD/M_T); the "relative antenna calibration" (file IGS_01.pcv). For local applications this has worked very well, however, for global high accuracy network applications this has caused some problems.

Current GPS antenna calibration techniques (anechoic chamber and robotic calibration) can determine the "absolute" position of the measurements within an antenna. The calibrations are generally expressed as a function of the azimuth and elevation. These antenna calibrations allow for the accurate correction of the GPS signal received/measured at an antenna/receiver to one physical reference location. Local conditions, (e.g. multipath) also affect the physical location of the phase center measurements. As will be seen below, processing strategy may also affect the position variations of the marker location as a function of the phase center model. To work properly, consistent satellite absolute antenna phase models also need to be used along with the station absolute antenna models (Schmid, 2005). Those were originally estimated by TUM and validated by GFZ. The tables available for the test (file IGS_05.pcv) did include consistent satellites/stations absolute phase center corrections. When implemented, this change will cause a discontinuity on all the IGS station coordinates time series, also potentially on the ERP and apparent geocenter time series. Although, implementation procedure may minimize this effect on the products, update of the IGS reference frame realization network and upcoming switch to the ITRF2005 will also likely cause some discontinuities. To avoid discontinuities at only a few months interval, it was agreed to combine all those changes at the same time. The following sections describe the analysis strategy followed by the discussion of the results.

Analysis Strategy

The main objective here is to implement an IGS reference frame realization that is consistent with the absolute phase center model. The entire official ACs weekly, GNAACs weekly, IGS weekly and cumulative solutions that have been generated until now have been using relative antenna phase center models. The reference frame realizations have in the past been extracted either from IGS cumulative solutions or ITRF solutions again derived from weekly solutions using relative antenna phase center models. The calibration model change affects mainly the height component (or scale) and need to be accounted for in the realization. The effect on the orbit products is addressed in Gendt and Nischan., [2006]. Small horizontal components are also present (20-25% of vertical). As mentioned above, the switch is also to a lesser extent dependant on the processing strategy and the network effects.

A call for participation was issued in the spring of 2005, where the ACs were asked to prepare weekly solutions of the final IGS products using the absolute antenna phase center model; the satellite phase center values were to be fixed or constrained to their nominal values. All other variables in the processing strategy had to be identical to those used during the official IGS products generation. By comparing the official solutions and the parallel run solutions for each participating AC, the effect of phase center model change could be estimated. The differences between the participating ACs solutions were also estimated. It was found that some solutions needed to be realigned (translation and rotation) to the reference frame realization before the effect of the phase center change could be properly estimated.

The proposed realization also needs to be consistent with the ITRF2005 in origin, orientation and scale (and their rates). Let’s first consider the height (scale) component. The IGS reference frame realizations scale (and rate) has been aligned to ITRF; which uses VLBI and SLR for its scale determination. One cannot simply correct the marker height to account for the phase center change and remain consistent with the ITRF scale. One way to maintain the IGS reference frame realization consistency with ITRF and still account for the relative phase center change is to apply a station by station phase center correction and rescale the results. To also account for the smaller horizontal components, rotations and translations are also estimated and applied. Because the rates should be insensitive to the phase center shift, transformation rates were not estimated.

Results

The ACs were invited to submit solutions with absolute antenna phase center corrections starting on 05/05/29 (GPS week 1325). COD, EMR, GFZ, MIT, NGS and SIO have been contributing to the test campaign. During the test phase from 05/05/29 to 05/09/17 (GPS weeks 1352-1340), some ACs did make some modifications to their software and resubmitted their solutions. The first iteration of the reference frame realization update was prepared at the end of 2005, which used the strategy described in the previous section. It was based on IGb00 and a subset of its original 99 stations, and was made available for testing. The more recent iterations have been using preliminary solutions of the ITRF2005 (Altamimi, 2006) and has also been made available for testing. The latest iteration did include weeks up to 06/03/04 (GPS week 1364). The test weeks were included in the analysis because the retained ACs (COD, EMR, GFZ and MIT) did show consistent results (<1mm) before and after the test phase. The effect of the antenna calibration change on the coordinates (ΔN, ΔE, ΔH) was computed at each station, each week and for each contributing AC. An example of such position variation differences time series can be seen for the case of ALGO in Figure 1.

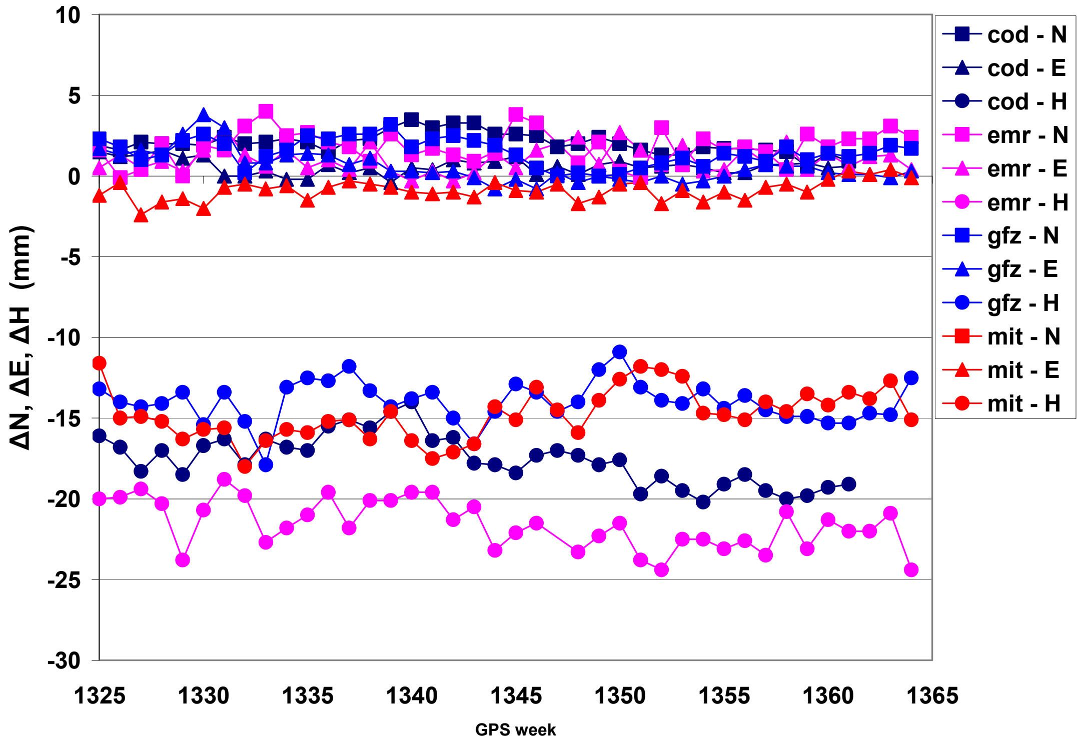

Figure 1. Position variation (ΔN, ΔE, ΔH) at ALGO caused by the the phase center variation model change from IGS_01 to IGS_05.

This is fairly typical time series of station position variations. As expected, the effect is mostly in the height component. Within an AC time series, the position variations are consistent. Between ACs there are often biases that can reach several mm. The IGS_01 model was used in the official solution, and the IGS_05 model (Schmid, 2006) was used for the test solutions by the contributing ACs. Note also that the networks used by the ACs for the tests and the official solutions were not identical, although very similar.

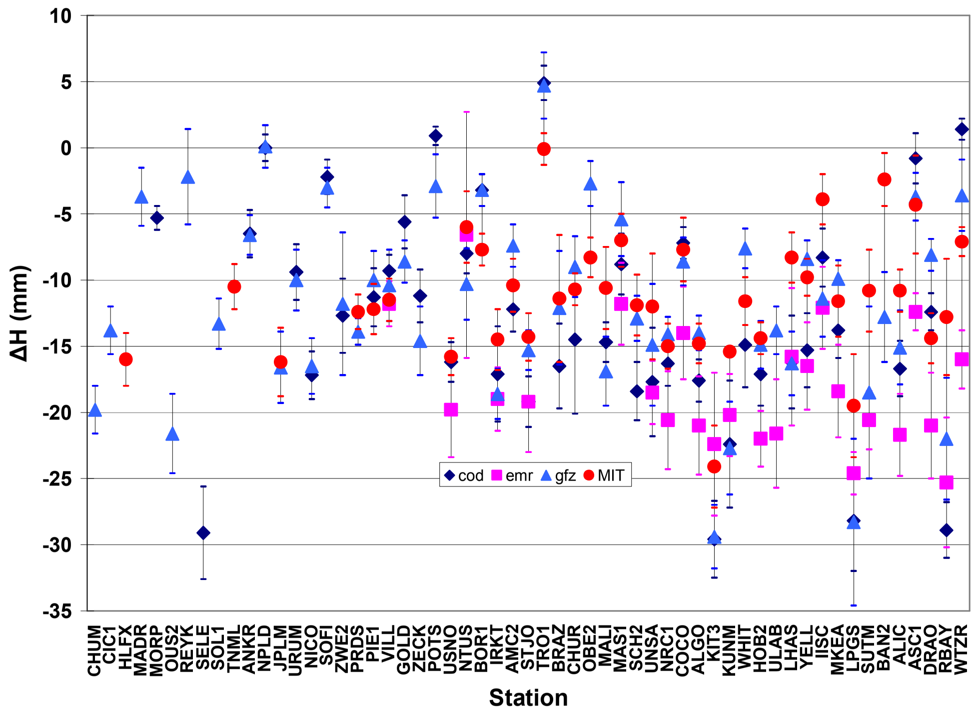

Figure 2. ΔH variations estimated by COD, EMR GFZ and MIT at IGS stations using AOAD/M_T antennas (without radome).

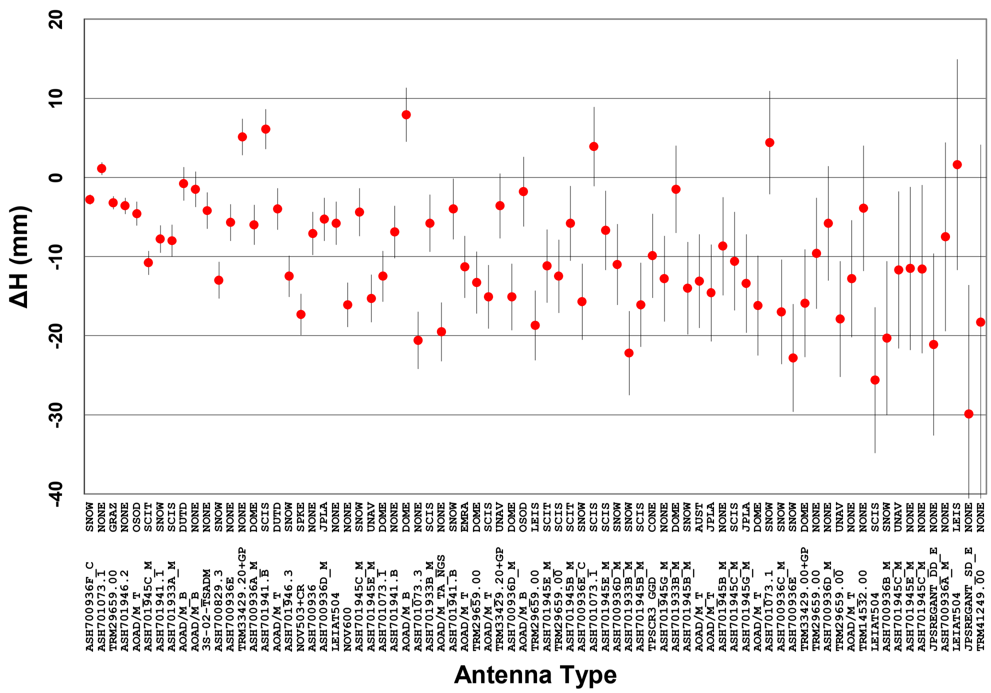

Figure 3. Antenna height offsets caused by the change from relative to absolute phase center model.

Figure 2 shows the variations between the COD, EMR, GFZ and MIT solutions at all (57) available stations using AOAD/M_T antennas without radomes. This antenna type has been chosen here as an example of the observed behavior, because it is the most commonly used in the IGS network and also because it was used as the reference in the relative antenna phase calibrations. The figure shows for each AC, the average ΔH along with the formal error (1 sigma). Those statistics are determined from the time series for the GPS weeks 1325 to1364 of the available weekly estimates. Station usage by each AC also varies somewhat from week to week. The stations in the figure are sorted by order of consistency between the AC estimates, where the consistency is determined by the difference between the largest and smallest AC average estimates. The consistency ranges from mm level to about 10mm. Processing strategy and network effects are probably the main cause of the consistency variations. The average ΔH value is 13mm ±7mm which correspond to about 2ppb. If we assume that the local effects accounts for most of the observed variations with respect to the average; they may account for 7mm. So for applications requiring the highest accuracy (<cm), the use of average values would not be sufficient to switch from relative to absolute phase center model.

Most antenna types have average corrections between 0 and 20mm as can be seen in Figure 3, with a weighted average of 12mm, again causing a scale offset close to 2 ppb. This is consistent with the results discussed above for the AOAD/M_T. This consistency is expected since these antennas were used as a reference for the relative phase center calibration. In the figure, the ΔHs are sorted by their formal uncertainty. One antenna type, “TRM29659.00 TCWD”, was not included in the series because of it unusual behavior.

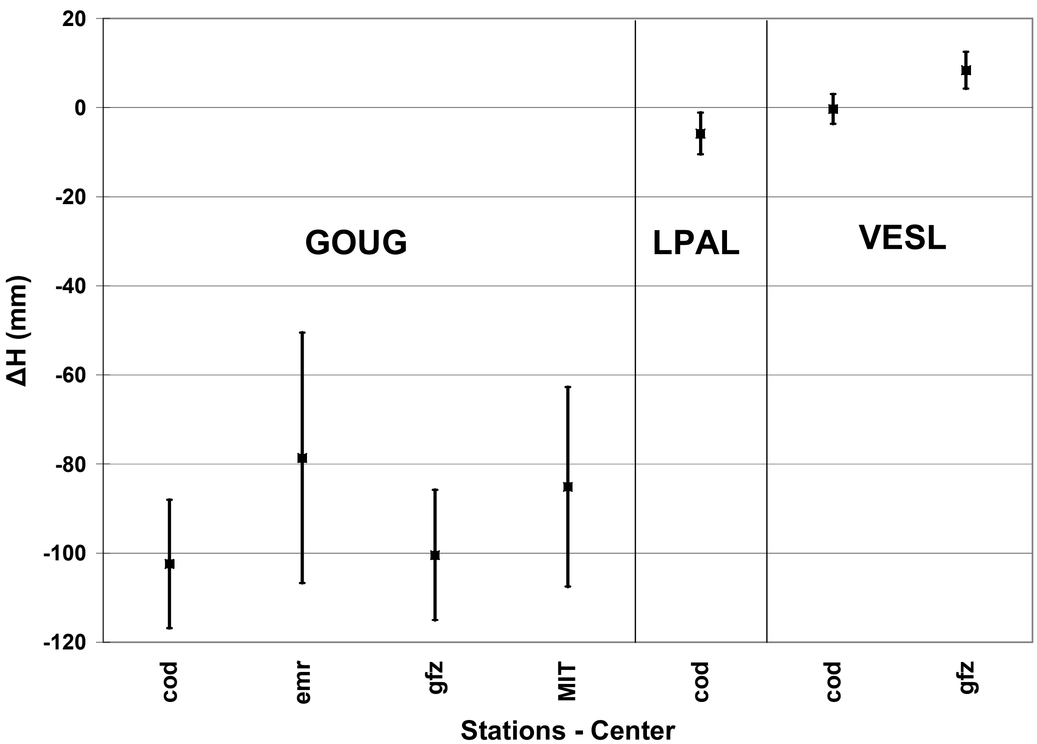

Figure 4. Relative to absolute phase center ΔH calibration for antenna type “TRM29659.00 TCWD”.

Figure 4 shows an unusual case that was observed at station GOUG using the “TRM29659.00 TCWD” antenna type. The estimated average relative to absolute antenna phase center correction ΔH is (-93.2 ±7.7mm). It was also used regularly by COD, EMR, GFZ and MIT. Their individual estimate are consistent with each other within ther noise level. It is by far the largest relative to absolute phase center correction ΔH. This type of antenna is also used at stations LPAL and VESL. The estimated ΔH at those sites is much smaller. This shows that ΔH can, in extreme cases, aproach 100mm, and so can they vary from station to station at that same level. Table 1 shows the relative to absolute antenna phase center corrections for the stations currently proposed for the realization of ITRF2005. Figure 5 illustrates the stations geographical distribution as well as the relationship with the current realization “IGb00”.

Table 1. Relative to Absolute Antenna phase center corrections for the IGS proposed realization of ITRF2005.

Station	**Antenna Type**	**ΔN**	**ΔE**	**ΔH**	**Station**	**Antenna Type**	**ΔN**	**ΔE**	**ΔH**
		(mm)	**(mm)**	**(mm)**			**(mm)**	**(mm)**	**(mm)**
ALGO	AOAD/M_T NONE	1.4	0.4	-17.4	MAW1	AOAD/M_T AUST	3.5	-1.6	-10.7
ALIC	AOAD/M_T NONE	0.2	0.0	-14.3	MBAR	ASH701945B_M SCIS	2.4	-0.6	-17.2
ALRT	ASH701945C_M NONE	1.6	1.2	11.6	MCM4	AOAD/M_T JPLA	0.9	-1.3	-5.2
AMC2	AOAD/M_T NONE	1.4	1.9	-11.1	MDO1	AOAD/M_T JPLA	3.7	2.4	-20.6
ARTU	ASH700936D_M DOME	-1.5	0.5	-15.7	MDVJ	JPSREGANT_DD_E NONE	-4.1	0.2	-15.2
ASC1	AOAD/M_T NONE	1.3	3.0	-4.7	METS	AOAD/M_B NONE	-0.6	-0.8	-2.0
ASPA	TRM33429.20+GP UNAV	1.7	-1.4	-3.9	MKEA	AOAD/M_T NONE	3.3	-1.4	-13.8
BAHR	ASH700936B_M SNOW	1.2	0.5	-15.6	NICO	AOAD/M_T NONE	3.0	-1.2	-17.7
BAKO	TRM14532.00 NONE	-0.9	-2.2	-9.8	NKLG	TRM29659.00 NONE	0.8	-2.7	-13.5
BILI	ASH701933B_M DOME	-0.3	-2.0	2.2	NLIB	AOAD/M_T JPLA	0.7	1.3	-14.7
BJFS	ASH700936B_M SNOW	0.7	-2.0	-26.8	NOT1	TRM29659.00 NONE	-0.4	-3.4	-10.5
BOR1	AOAD/M_T NONE	0.2	-0.2	-5.6	NOUM	TRM41249.00 NONE	-1.2	0.9	-7.9
BRAZ	AOAD/M_T NONE	2.7	2.5	-12.5	NOVJ	JPSREGANT_SD_E NONE	-5.8	3.1	-33.3
BRMU	TRM29659.00 UNAV	4.4	3.8	-26.4	NRC1	AOAD/M_T NONE	1.4	0.6	-16.5
BRUS	ASH701945B_M NONE	-0.3	-0.2	-4.4	NRIL	ASH701945B_M SCIT	-0.7	-1	-3.9
CAGL	TRM29659.00 NONE	-0.9	-2.1	-4.2	NYA1	ASH701073.1 SNOW	0.1	-0.2	8.6
CAS1	AOAD/M_T AUST	3.1	-1.5	-7.3	NYAL	AOAD/M_B DOME	0.9	0.3	7.6
CEDU	AOAD/M_T AUST	0.1	-0.3	-20.2	OHI2	AOAD/M_T DOME	2.2	1.5	-10.5
CHAT	ASH701945C_M NONE	2.4	-0.7	-18.8	OHI3	ASH701941.B SNOW	5.8	0.8	-3.1
CHPI	ASH701945C_M NONE	2.0	3.0	-13.0	ONSA	AOAD/M_B OSOD	-0.3	-0.5	-2.2
CHUR	AOAD/M_T NONE	-0.4	1.6	-12.5	OUS2	AOAD/M_T NONE	2.0	-0.9	-20.8
COCO	AOAD/M_T NONE	1.3	-2.2	-9.1	PDEL	LEIAT504 NONE	0.9	3.5	-5.7
CONZ	TPSCR3_GGD CONE	2.5	1.8	-12.5	PERT	ASH701945C_M NONE	0.9	-2.2	-20.9
CORD	ASH701945G_M NONE	2.6	1.2	-9.8	PETP	AOAD/M_T DOME	0.0	-0.1	-14.6
CRO1	ASH701945G_M JPLA	2.0	0.5	-20.3	PIE1	AOAD/M_T NONE	1.7	1.7	-12.1
DAEJ	TRM29659.00 DOME	0.2	-2.5	-16.0	PIMO	ASH701945C_M NONE	2.2	-1.8	-21.7
DARW	ASH700936D_M NONE	0.5	-0.6	-13.9	POL2	ASH701945C_M NONE	-0.8	0.4	-18.0
DAV1	AOAD/M_T AUST	3.0	-0.6	-9.2	POLV	TRM29659.00 NONE	-0.6	-1.3	-1.4
DGAR	ASH701945E_M NONE	0.9	1.0	-5.5	POTS	AOAD/M_T NONE	-0.1	-0.6	-2.3
DRAO	AOAD/M_T NONE	1.6	1.1	-13.3	QAQ1	ASH701945E_M SCIS	0.4	1.3	-7.4
DUBO	AOAD/M_T SCIS	-0.2	1.9	-19.2	QUIN	AOAD/M_T JPLA	3.2	1.2	-9.7
FAIR	ASH701945G_M JPLA	1.5	-0.7	-10.9	RABT	TRM29659.00 SCIS	-0.5	-1.6	-10.2
FLIN	AOAD/M_T SCIS	-0.4	1.6	-12.1	RAMO	ASH701945B_M SNOW	3.2	-0.5	-15.2
GLPS	ASH701945B_M SCIT	1.7	1.0	-9.0	RBAY	AOAD/M_T NONE	2.8	-1.8	-20.9
GLSV	TRM29659.00 NONE	-0.5	-3.2	-6.4	REUN	ASH701073.3 NONE	1.8	0.4	-20.2
GODE	AOAD/M_T JPLA	1.2	0.0	-16.0	REYK	AOAD/M_T NONE	-0.1	0.9	-3.0
GOLD	AOAD/M_T NONE	3.1	1.4	-7.6	RIOG	ASH700936C_M SNOW	1.6	0.5	-16.6
GOUG	TRM29659.00 TCWD	5.0	0.5	-93.2	SANT	AOAD/M_T JPLA	2.2	1.5	-10.1
GRAS	ASH701945E_M NONE	0.1	-0.9	-4.3	SCH2	AOAD/M_T NONE	0.9	1.0	-15.3
GUAM	AOAD/M_T JPLA	3.3	0.0	-15.6	SCUB	ASH700936C_M SNOW	1.6	-1.2	-15.1
GUAO	ASH701945B_M NONE	1.0	-1.0	-8.7	SEY1	ASH701945C_M NONE	1.2	-0.2	-11.7
HARB	TRM29659.00 NONE	1.6	-3.8	-15.3	SFER	TRM29659.00 NONE	-1.1	-1.8	-4.7
HLFX	AOAD/M_T NONE	1.0	0.7	-16.0	STJO	AOAD/M_T NONE	2.2	1.4	-17.1
HNLC	ASH700936D_M SNOW	2.2	1.0	-11.0	SUTH	ASH701945G_M NONE	3.2	-2.5	-12.2
HOB2	AOAD/M_T NONE	2.3	0.0	-15.2	SYOG	AOAD/M_T DOME	4.0	-0.3	-21.4
HOFN	TRM29659.00 NONE	-1.0	-0.4	-4.5	THTI	ASH701945E_M NONE	0.8	-1.0	-23.3
HOLM	ASH701945C_M NONE	0.6	0.3	-1.9	THU3	ASH701073.1 SCIS	1.7	1.0	2.9

Station	Antenna Type		ΔN	ΔE	ΔH	Station	Antenna Type		ΔN	ΔE	ΔH
			(mm)	(mm)	(mm)				(mm)	(mm)	(mm)
H R A O	ASH701945C_M	NONE	3.2	-2.1	-17.7	T I D B	AOAD/M_T	JPLA	1.1	-0.2	-17.1
H Y D E	ASH701945B_M	SNOW	2.0	1.7	-10.4	T I X I	ASH700936D_M	NONE	0.3	-1.0	-2.0
I I S C	AOAD/M_T	NONE	1.5	0.7	-9.0	T O W 2	AOAD/M_T	AUST	0.4	0.7	-11.5
I R K T	AOAD/M_T	NONE	-0.1	-1.3	-17.5	T R A B	ASH700936D_M	SNOW	0.5	-0.8	-17.3
I S P A	ASH701945E_M	SCIT	0.7	2.8	-11.1	T R O 1	AOAD/M_T	NONE	-0.6	-0.3	2.2
J A B 1	ASH701945C_M	NONE	0.6	-0.2	-15.0	T R O M	AOAD/M_B	NONE	-0.6	-0.8	-2.0
J O Z E	TRM14532.00	NONE	-1.6	-0.2	4.4	T S K B	AOAD/M_T	DOME	2.1	-0.8	-14.4
K A R R	AOAD/M_T	AUST	0.5	-1.6	-11.0	U L A B	AOAD/M_T	NONE	-0.4	-1.7	-18.0
K E L Y	ASH701945C_M	NONE	0.0	0.6	-1.6	U N S A	AOAD/M_T	NONE	1.8	1.1	-13.9
K E R G	TRM29659.00	NONE	2.6	-1.9	-18.5	U S N O	AOAD/M_T	NONE	1.6	0.5	-18.2
K I T 3	AOAD/M_T	NONE	1.1	0.7	-27.4	V E S L	TRM29659.00	TCWD	3.7	0.3	5.4
K O K B	ASH701945G_M	NONE	3.3	-1.7	-10.6	V I L L	AOAD/M_T	NONE	0.6	0.5	-11.0
K O U R	ASH701945C_M	NONE	2.1	1.7	-13.6	W E S 2	AOAD/M_TA_NGS	NONE	1.9	0.8	-20.2
K U N M	AOAD/M_T	NONE	2.0	-2.1	-22.4	W H I T	AOAD/M_T	NONE	0.3	0.0	-13.1
L A E 1	ASH700936A_M	NONE	1.6	0.9	-18.9	W I L L	AOAD/M_T	EMRA	0.5	0.8	-12.5
L H A S	AOAD/M_T	NONE	0.4	-0.9	-13.5	W S R T	AOAD/M_T	DUTD	-0.1	-0.3	-4.6
L P G S	AOAD/M_T	NONE	1.8	0.8	-24.4	W T Z R	AOAD/M_T	NONE	0.2	-0.4	-4.3
M A C 1	AOAD/M_T	AUST	2.9	-0.2	-19.4	W U H N	ASH700936E	SNOW	0.6	-3.0	-23.3
M A D R	AOAD/M_T	NONE	0.2	-0.1	-5.7	Y A R 1	AOAD/M_T	JPLA	-0.1	-2.2	-12.5
M A L I	AOAD/M_T	NONE	1.8	-0.8	-13.8	Y E L L	AOAD/M_T	NONE	0.9	1.1	-13.2
M A N A	TRM29659.00	UNAV	4.3	2.7	-18.2	Y S S K	ASH701933B_M	DOME	0.3	-1.8	-7.5
M A S 1	AOAD/M_T	NONE	1.6	2.4	-8.4	Z I M M	TRM29659.00	NONE	-1.2	-2.7	-3.0
M A T E	TRM29659.00	NONE	-0.7	-1.4	-10.6						

As mentioned in the analysis strategy, the IGS proposed realization of ITRF2005 for use with absolute antenna phase center processing includes Table 1. A 7-parameters transformation was also estimated and applied to correct for small misalignments that the antenna phase center correction may cause. The estimated transformation parameters are given in Table 2. As expected, the most significant effect is in the scale. The RMS of the residuals in the N, E, H components are (1.5mm, 1.3mm, and 9.9mm). These results are for the release dated “06/06/06”.

Table 2. Transformation from the IGS realizations of ITRF using “relative” and “absolute” antenna phase center.

TX	TY	TZ	RX	RY	RZ	SC
(mm)	(mm)	(mm)	(mas)	(mas)	(mas)	(ppb)
1.7	0.0	2.3	-0.010	-0.005	-0.003	-1.98

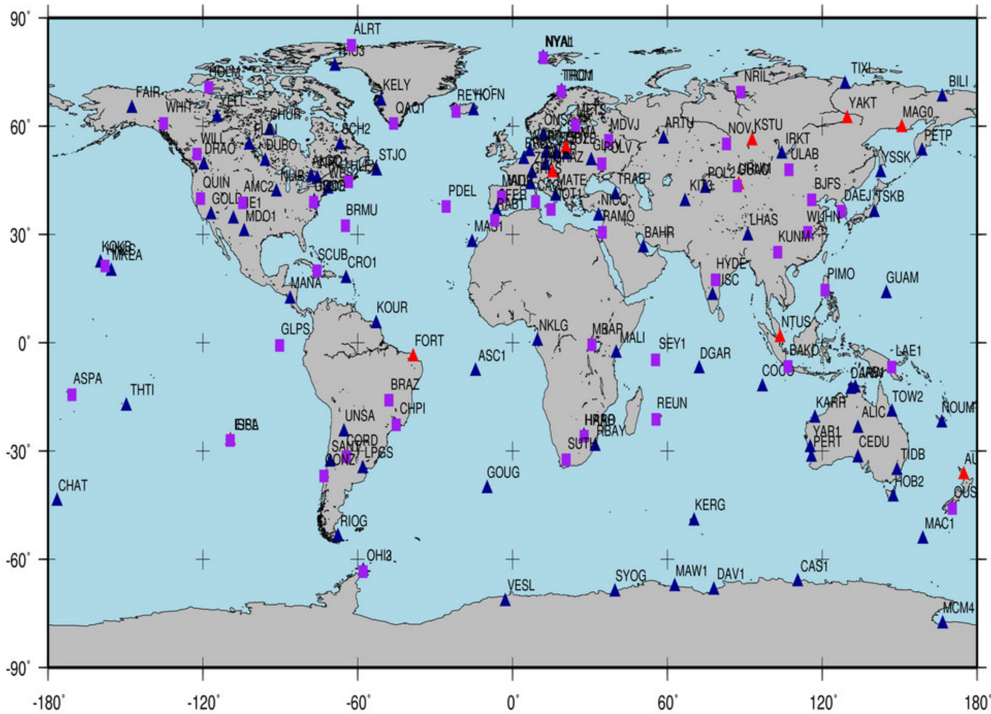

Figure 5. Proposed realization of frame IGS05.

The proposed realization was first tested using the IGS weekly combined official solutions. In this first test, the proposed realization and the weekly solutions for GPS weeks 1340 to 1370 are using the antenna relative phase centers. All ACs (COD, EMR, ESA, GFZ, JPL, MIT, NGS and SIO) contributed to the IGS weekly solutions. The proposed realization was propagated to the epoch at middle of the week corresponding to each weekly solution. The weekly solutions were aligned to the proposed realization of the corresponding epoch and the residuals were estimated. The standard deviation of those residuals (N, E, H) is (1.9mm, 1.8mm, 5.7mm).

A similar test was repeated with the proposed realization using antenna absolute phase centers. This time, the weekly combination included test solutions from COD, EMR, GFZ and MIT only. GPS weeks 1340 to 1370 were compared in the same way as above. The standard deviation of the residuals is 2.1mm, 1.9mm, 5.8mm. Those are almost identical in this latest proposed realization. This indicates that this latest iteration of the absolute phase center realization doesn't add any significant noise to the IGS realization.

The proposed realizations using relative and absolute antenna phase center were used to align the official and the test solutions for GPS weeks 1340 to 1370. The daily pole position differences between the absolute phase center and relative phase center realizations are in X, 0.007 ± 0.011mas and in Y, 0.012 ± 0.014 mas. This indicates that the phase center change should produce an effect on the pole position at or less than 0.01mas.

SUMMARY

The effect of the switch from relative to absolute antenna phase center corrections was estimated from "parallel" solutions provided by a subset of the contributing ACs (COD, EMR, GFZ, MIT, NGS and SIO). Those parallel solutions were computed using absolute phase center corrections, while the production solutions were computed using relative phase center corrections. In principle, the only difference between the "official" (relative) and the "test" (absolute) solutions were the phase center models. The effect of the phase center model change could then be estimated by comparing the corresponding solution pairs. Solutions from GPS weeks 1325 to 1364 were used to estimate the differences at all stations in the update to the proposed reference frame stations network. The standard deviation of the residuals between the proposed realization (relative and absolute) and the weekly solutions are about 2mm/6mm in the horizontal/vertical components. The effect on the pole position is about 0.01mas.

The effect on station coordinates was, as expected, mainly on the height component. The average height differences correspond to a scale change of about 2ppb, which brings the current IGS "scale" closer to ITRF. Height variations at stations using the same type of antenna reach the cm level. Similar differences were also observed between different antenna types. Biases, sometimes exceeding 10mm, were observed between the ACs average differences.

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