Position Corrections due to Uncalibrated GNSS Antenna Radomes at IGS Co-located Geodetic Observing Stations

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Abstract

The International GNSS Service (IGS) through the Infrastructure Committee, the Analysis Center Coordinator, the Antenna Working Group, the Reference Frame Working Group and the Central Bureau have organized a campaign from 2011 to 2013 to analyze the unknown bias in the estimated position for co-located stations due to an uncalibrated radome over the GNSS antenna. Co-located stations have more than one geodetic technique present (GNSS, VLBI, SLR, etc.) and they are a critical element for the realization of the ITRF. Due to the use of uncalibrated radomes over the GNSS antennas at these important sites the "local ties" between techniques do not have the expected accuracy, and therefore a campaign to analyze the different radome effects was planned and executed at many of the affected IGS stations.

The proposed approach is an expedient way to mitigate empirically an unwanted situation with these uncalibrated radomes in the IGS station network so as to try to improve the historic position time series of these stations for the next ITRF realization. The process has involved removing the uncalibrated radome for a significant number of weeks and then putting the radome back on in the exact same position. The investigation proceeds with dedicated PPP analyses from different sources plus a detailed analysis of the weekly IGS station position combinations. This poster presents the campaign approach, the participating stations and the results.

Stations Affected

Covering a GNSS antenna with a radome whose phase center variations (PCVs) have not been calibrated will usually cause an unknown bias in the estimated position for that station. This bias is equivalent to a local tie error for those IGS stations co-located with other techniques and is thus a serious concern for ITRF, which aims for tie accuracies at the 1 to 2 mm level. Radome effects can often be much larger, up to several cm. Therefore these uncalibrated radomes prevent an accurate connection between co-located space geodetic instruments and weaken the ITRF.

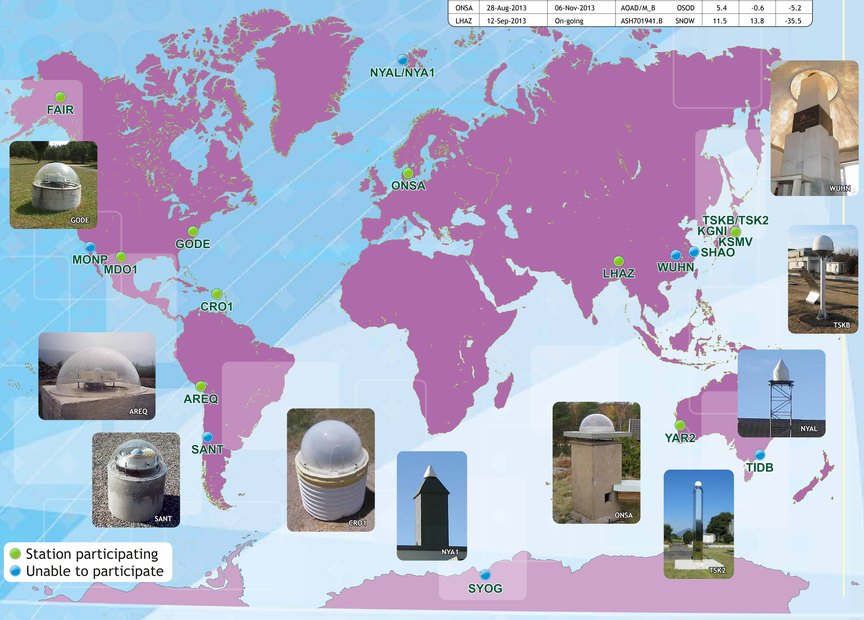
Absolute tie discrepancies from ITRF2008 reach up to 32 mm in North, 16 mm in East, and 99 mm in Up, although technique and tie survey errors also contribute to these. Every effort is needed at this time to reduce the uncalibrated radome effect.

This proposal considers only those uncalibrated radomes **at stations that are co-located with SLR or VLBI observatories**. Non-co-located stations and those near DORIS stations are NOT considered here. However, operators are strongly urged to please arrange to calibrate the uncalibrated equipment or replace it as soon as possible (please coordinate with the IGS Central Bureau and the IGS Infrastructure Committee).

STATION PARTICIPATION

	Radome Removal	Re-installation	Antenna		ITRF2008 Tie Discrepancy (mm) E	N	U
CRO1	01-Apr-2011	24-Jun-2011	ASH701945G_M	JPLA	-1.5	2.2	1.6
TSKB	01-Jul-2011	30-Aug-2011	AOAD/M_T	DOME	-2.9	-0.8	-3.0
TSK2	01-Jul-2011	30-Aug-2011	TRM29659.00	DOME			
AREQ	19-Aug-2011	03-Feb-2012	AOAD/M_T	JPLA	1.3	-0.3	-6.6
FAIR	28-Apr-2012	04-Aug-2012	ASH701945G_M	JPLA	-2.3	-8.2	2.1
YAR2	23-May-2012	28-Sep-2012	AOAD/M_T	JPLA	3.3	-1.9	14.4
GODE	06-Jul-2012	13-Dec-2012	AOAD/M_T	JPLA	-3.2	1.2	-6.1
MDO1	22-Feb-2013	09-Aug-2013	AOAD/M_T	JPLA	4.4	-8.3	17.5
ONSA	28-Aug-2013	06-Nov-2013	AOAD/M_B	OSOD	5.4	-0.6	-5.2
LHAZ	12-Sep-2013	On-going	ASH701941.B	SNOW	11.5	13.8	-35.5

Radome-Off Test Stations



Proposal

All Station Operators of the stations listed in the map below, have been asked to reply with one of the following designations for each of their stations (in order of decreasing preference):

1. **Calibration planned.** Uncalibrated equipment of exact same type will be calibrated for the absolute PCVs. Please provide details of the arrangements being made and when calibration results are expected. If duplicate uncalibrated equipment (antenna+radome) is not available, then it might be advisable to calibrate the actual equipment in use.
2. **Radome can be removed and reinstalled.** Please schedule a period to remove the uncalibrated radome for a period of at least 8 weeks to make an empirical measurement of the radome bias offset effect. See details below.
3. **Radome cannot be reinstalled if removed.** Please provide details. In this case, we ask that operators arrange to install calibrated replacement equipment at the earliest opportunity. BUT BEFORE DOING SO, please arrange to remove the radome for an 8-week period just before the new equipment is installed in order to determine the empirical radome offset to correct the historic time series.
4. **Radome cannot be removed without destroying entire antenna assembly.** Please provide details. In this case, we ask that operators arrange to install calibrated replacement equipment at the earliest opportunity. For these stations the historic time series will never be reliable for local ties between techniques.

Station Operators have agreed only with **Option 2** as most assemblies are not subject to calibration either with a field robot or in a chamber.

Procedure

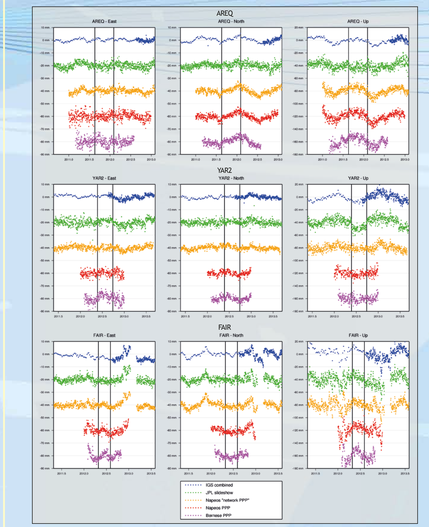
The participating stations are well suited for the proposed empirical offset calibration (**Option 2**, above), which can provide a correction for the local tie vector to other techniques, similar to what was done at Fortaleza, Brazil in 2005 (**http://acc.igs.org/misc/brft-gpssoln07.pdf**) the following procedure has been recommended:

1. **Scheduling.** Each station will schedule an 8-week period, or more, during which the uncalibrated radome will be removed. Users will be notified of plans via IGS Station Mail and site logs should be updated accordingly.
2. **Radome Removal.** The uncalibrated radome should be removed late in the week before the radome-free period begins, preferably Saturday or Friday, since IGS analyzes data for each Sunday to Saturday period.
3. **Radome-Free period.** Normal operations for the station with no radome in place will continue for 8 weeks, or more, to allow an accurate determination of the position shift. The stations will continue to be included in the Analysis Center position estimation (SINEX solutions), and the Reference Frame WG is fully aware that discontinuities may have to be included as needed in the position time series of the stations.
4. **Radome re-installation.** The radome should be re-installed at the beginning of a week, Sunday or later. The re-installation shall be announced via IGS Station Mail and site logs should be updated accordingly.

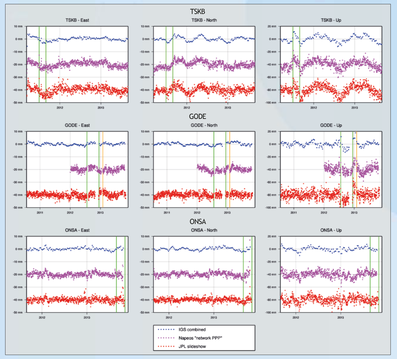
Analysis

The station positions before and after the radome removal have been estimated using different programs using global network solutions with dual-frequency data in order to be fully sensitive to the same biases as normal IGS solutions. For the analysis so far the following solutions have been considered and the resulting SINEX files analyzed to try to estimate the radome effects:

1. The weekly/daily IGS Analysis Center combined coordinates
2. JPL's daily position time series (http://sideshow.jpl.nasa.gov/post/series.html)
3. Daily "Network PPP" with ambiguities fixed from Napeos (ESA/ESOC Analysis Center GNSS software)
4. Daily single-station PPP solutions from Napeos
5. Daily single-station PPP solutions from Bernese



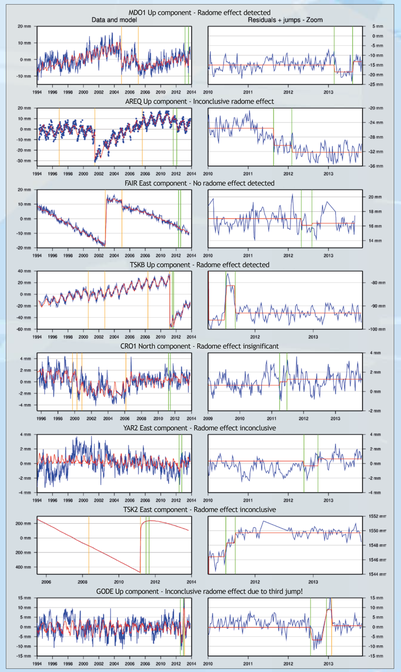
After the initial analysis of all the solutions the most consistent ones were retained (1, 2, 3) and the analysis extended to cover a longer period after the radome re-installations;



The station positions have been analyzed as follows; for stations that have earthquakes in the historical time series an exponential relaxation model function is used plus for some station components a logarithmic post-seismic relaxation is also applied. Additionally on each station coordinate component a parametric model is estimated consisting of:

- one constant velocity
- piece-wise constant offsets
- periodic signals at the annual, semi-annual and at the first six draconitic harmonics

additionally outliers were iteratively removed. The coordinate estimations and residuals of some of the affected coordinate components around the radome removal/re-installation can be seen below. On the left the long term time series (blue dots) are used to determine the correction models (red line) as described above, per coordinate component. On the right using the residuals after removing the model the effect of the uncalibrated radome is extracted with an estimated jump. If the jump before and after is consistent a real radome effect can be concluded.



The orange lines indicate known time series discontinuities. The green lines indicate the radome removal/re-installation for this experiment.

Bibliography

Altamimi Z, Collilieux X, Métivier L (2011) ITRF2008: an improved solution of the international terrestrial reference frame. J Geod 85(8):457-473, DOI 10.1007/s00190-011-0444-4

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Results

Two stations have been added to the experiment late in 2013 (ONSA, LHAZ), which means that more data will be analyzed in the coming months, but for the stations that have had the radome removed/re-installed some time ago it is possible to estimate the jump in station coordinate components due to the radome as presented in the table below.

RADOME EFFECTS

Station	Comp.	Estimated jumps (mm) At radome removal	At radome re-installation	WRMS (mm)	Remarks	
AREQ	East	+1.0 +/- 1.2	-0.7 +/- 1.2	0.9	Not significant	
	North	+2.0 +/- 3.1	-1.2 +/- 3.1	0.9	Not significant	
	Up	-4.8 +/- 1.1	-1.9 +/- 1.2	2.3	Inconclusive (post-seismic relaxation)	
CRO1	East	+0.7 +/- 0.9	-1.8 +/- 1.0	1.7	Inconclusive (low frequency noise)	
	North	+0.4 +/- 0.5	+0.3 +/- 0.6	1.0	Not significant	
	Up	+0.1 +/- 1.8	-4.1 +/- 2.0	3.5	Inconclusive (low frequency noise)	
FAIR	East	-0.9 +/- 0.7	+0.3 +/- 0.7	1.1	Inconclusive	
	North	-0.8 +/- 1.0	-0.2 +/- 1.0	1.6	Not significant	
	Up	-0.1 +/- 2.0	-3.2 +/- 2.2	4.7	Inconclusive	
GODE	East	+0.4 +/- 0.4	-1.1 +/- 0.6	1.1	A 3rd jump due to another radome manipulation follows the radome re-installation. This makes the estimation and interpretation of the radome jumps inconclusive. Estimated 3rd jump:	+1.1 +/- 0.6
	North	+0.3 +/- 0.4	+1.0 +/- 0.6	1.1		-0.4 +/- 0.6
	Up	-6.5 +/- 1.1	15.6 +/- 1.8	3.3		-8.3 +/- 1.6
MDO1	East	+2.0 +/- 0.5	-4.8 +/- 0.6	1.4	Estimated jumps not reliable.	
	North	-8.9 +/- 0.6	+2.9 +/- 0.8	2.1	Inconclusive (low frequency noise)	
	Up	8.7 +/- 1.0	-5.5 +/- 1.3	3.2		
TSK2	East	+1.9 +/- 9.6	+1.4 +/- 9.4	0.6	Inconclusive (post-seismic relaxation)	
	North	+0.4 +/- 4.5	+1.1 +/- 4.3	0.7	Inconclusive (post-seismic relaxation)	
	Up	+3.4 +/- 6.2	-16.5 +/- 6.8	2.6	Inconclusive (post-seismic relaxation)	
TSKB	East	-2.1 +/- 15.8	+0.0 +/- 15.3	1.4	Inconclusive (post-seismic relaxation)	
	North	-2.7 +/- 1.3	-2.7 +/- 1.8	1.0	Inconclusive (low frequency noise)	
	Up	+14.8 +/- 1.9	-11.8 +/- 2.6	2.7		
YAR2	East	-0.7 +/- 0.4	+1.0 +/- 0.4	1.1	Inconclusive (low frequency noise)	
	North	+0.0 +/- 0.4	+0.9 +/- 0.4	1.1	Inconclusive (low frequency noise)	
	Up	-2.3 +/- 1.1	+3.5 +/- 1.2	3.4	Inconclusive (low frequency noise)	

Only two of the estimated radome jumps can be considered as credible at this time (MDO1 and TSKB in Up) they are not fully in-line with the tie discrepancies reported in ITRF2008 (see Station Participation Table), but they could still be useful in improving coordinate estimates from different space geodesy estimates. As for the other stations many of the other estimated radome-induced jumps are not consistent (before and after) and so the estimated jumps are likely simply absorbing low frequency time series noise or post-seismic relaxation not properly absorbed in the exponential and logarithmic models.

There have also been significant issues in coordinating and executing the experiment as many different and disparate organisations had to be brought along. In the end the participation of 10 stations can be considered a success but implementation problems of the proposed procedure has meant that the experiment was compromised at certain stations (i.e. GODE: where additional antenna manipulation during and after the "radome off" has created a very complex situation for analysis, CRO1: where the radome manipulation took place during the transition in the IGS from ITRF05 to ITRF08 introducing more uncertainty than needed).

It is clear from the estimated jumps presented in the table above that it is not possible to properly separate the residual noise from the "radome-induced jumps" at the majority of the sites with the global solutions analyzed to date.

Conclusions

There are a number of critical IGS stations co-located with other geodetic techniques which suffer from discrepancies between space geodesy estimates and terrestrial local ties. The ITRF aims for tie accuracies of a few millimeters and uncalibrated radomes can have much larger effects. To quantify the uncalibrated effect this experiment has been devised by the IGS Infrastructure Committee, Reference Frame WG, Antenna WG, Analysis Center Coordinator and the Central Bureau.

This IGS Radome-off experimental campaign has been a success in bringing together in a common action many different and disparate organisations which manage the individual co-located stations. Unfortunately the effect of the uncalibrated radomes cannot be extracted in most cases from the global solutions analysed up to this point. Even when complex correction models are applied to the coordinate time series, the estimated "radome-induced jumps" are generally within the residual time series noise.

Two more stations have been added late in the experiment (ONSA and LHAZ) and they will be processed in the coming months. Additional short baseline processing will be tried for all the participating stations over the radome removal/re-installation periods. With the aim of trying to extract the uncalibrated radome effect on the station position to improve the "co-location ties" as much as possible.

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