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[IGSMAIL-5189]: Planned changes to IGS antenna calibrations

- *To*: IGSmail <igsmail @ igscb.jpl.nasa.gov>
- *Subject*: [IGSMAIL-5189]: Planned changes to IGS antenna calibrations
- *From*: Gerd Gendt <gend @ gfz-potsdam.de>
- *Date*: Wed, 17 Aug 2005 13:28:13 +0200 (CEST)
- *Sender*: owner-igsmail

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Author: Gerd Gendt and Ralf Schmid

This message is to alert users of pending changes that will profoundly affect
IGS products. The changes concern the conventions for handling phase
corrections due to antenna effects. The related activities go back to the 2002
IGS Workshop in Ottawa [Rothacher and Mader, 2003] and were put into concrete
recommendations during the Workshop in Berne last year [Schmid et al., 2005a].
Even data analysts who do not use IGS products directly should be aware of
these developments and should consider what changes, if any, are appropriate in
their own procedures.

Background
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Early in the era of GPS geodesy it was appreciated that the phase response of
GPS tracking antennas does not correspond to an ideal point source. That is,
with respect to a fixed reference point within the antenna, the signal
wavefronts of constant phase do not form perfectly hemispherical shells.
Instead, the phase can vary depending on viewing direction (elevation and
azimuth angles toward the satellite being observed). Since most high-quality
antennas are manufactured to tight physical specifications, the variations
between different models are generally much larger than among different
replicas of the same model. For the highest quality of geodetic results, it is
therefore necessary to account for these antenna effects in the data analysis
based on antenna type. Otherwise errors of up to several cm can occur in
estimates of the antenna position.

Relative antenna corrections
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Despite this realization, the application of antenna phase center corrections
measured in anechoic chambers [e.g., Schupler et al., 1994] was found to give a
global GPS frame differing from VLBI and SLR in scale by about 15 ppb,
equivalent to a global height shift of ~10 cm. (Note that a +1 ppb change of
the terrestrial scale corresponds to a uniform height shift of +6.4 mm.) This
was considered an unreasonably large discrepancy, considering the good
agreement between VLBI and SLR, so the chamber measurements were not adopted
for general use.

Nevertheless as new antenna types joined the IGS network, which was initially
dominated by the AOA Dorne-Margolin choke ring models, it became necessary to
somehow account for differences in the phase responses. After extensive
discussions, it was agreed at the IGS Analysis Center Workshop held at Silver
Spring (19-21 March 1996) that relative phase center corrections would be
applied by 30 June 1996. The corrections were to be determined using
short-baseline field measurements wherein the "AOAD/M_T" antenna was taken to
be the defining standard [Mader, 1999]. For each antenna model, a NEU offset
value was adopted for the mean location of the antenna electrical reference
center compared to the external, physical, antenna reference point (ARP).
Relative to this mean phase center, the antenna phase center variations (PCVs)
were then measured as a function of elevation angle. Using this method the
elevation range for PCVs has been limited to 10 degrees due to ground noise.
The results have been maintained since that time for IGS and general use in the
file:
   ftp://igscb.jpl.nasa.gov/igscb/station/general/igs_01.pcv

As new antenna models have become available, new calibration measurements have
been added to the file before the antenna could be included in the IGS network.

It was generally recognized that the approach of using relative antenna
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calibrations was an expedient made necessary to avoid cm-level errors, but it was not a complete or permanent solution. For one thing, the relative calibration measurements are really valid only for short baselines. Even for the same antenna model, on long baselines a satellite is viewed from markedly different elevation angles so the relative PCVs are not adequate [Mader, 1999]. Furthermore, the discrepancy in the GPS frame scale must ultimately be understood and addressed. Note that even with the relative PCVs the current IGS terrestrial frame is smaller than ITRF2000 (before rescaling) by nearly 3 ppb (see the weekly IGS SINEX combination reports by R. Ferland) and that the scale of the GPS frame has varied with time by more than 1 ppb in 2000 [Ge et. al., 2005].

Absolute antenna corrections

It was suggested by several people that neglect of any non-ideal effects in the satellite antennas might explain the apparent failure of chamber PCVs. Since it has not been feasible to measure independently the satellite antenna characteristics very accurately [Mader and Czopek, 2002], those properties must be determined from the GPS data together with other usual geodetic parameters. Springer [2000] was the first to demonstrate quantitatively the difficulties of the problem due to very high correlations among tracking antenna offsets and PCVs, satellite antenna offsets and PCVs, estimated station heights, and estimated tropospheric parameters. Due to these correlations, the general problem is singular. A solution is possible if the terrestrial frame scale is fixed by adopting a set of fiducial coordinates for the tracking network and if the "absolute" phase center corrections (offsets and PCVs) for the tracking antennas are known from external calibration measurements.

Meanwhile there exist absolute offsets and PCVs determined by a robotic system developed by the University of Hannover and the company Geo++ [Menge et al., 1998], which include azimuthal values and elevations down to 0 degrees. PCVs for those tracking antennas not measured by the robotic system have been inferred using the prior relative PCVs together with the absolute patterns for the AOAD/M_T antenna. These inferred patterns are still only valid to elevation angles of 10 degrees.

Schmid and Rothacher [2003] demonstrated that it is possible to determine satellite antenna offsets and PCVs if the absolute tracking antenna models and the station coordinates in ITRF2000 are fixed. The results have been independently validated by GFZ Potsdam [Ge and Gendt, 2005].

Recently, for the derivation of the 'official' IGS satellite antenna models (PCVs and offsets) 11 years of data were reprocessed by TUM and GFZ while aligning the solutions to IGb00. The solutions for the satellite offsets have a trend, which is caused by an error in the vertical rate of the IGb00 (~1 mm/y). Referencing the offsets to a given epoch (2000.0 in the antenna model) will stabilize the scale in the GPS network solutions. Tests with the new model have shown that the IGb00 has a scale rate of ~0.15 ppb/y compared to the new solutions, which is consistent with the reported vertical rate error of IGb00.

So, a complete and consistent set of absolute PCVs for both tracking and satellite antennas has been assembled. A test version of this set is available in the file (see IGS Mails #5149, #5187):
   ftp://igscb.jpl.nasa.gov/igscb/station/general/pcv_proposed/igs_05.atx
The file contains in total:
- 106 antenna calibrations, where
  - 14 are from Geo++ (elevation and azimuth, robot calibrated)
  - 16 with identical construction are copied from the above 14
  - 76 are from NGS (elevation only, converted form relative model)
- 45 antenna and radome calibrations
  - 10 are from Geo++ (elevation and azimuth, robot calibrated)
  - 35 are from NGS (elevation only, converted form relative model)

Among the 40 antennas possessing full calibration models (azimuthal PCVs and elevations down to 0 degrees) from robot calibrations are most of the antennas dominating the IGS tracking network. Converted relative calibrations have mainly been added for reasons of completeness and in order to facilitate the use of the file outside the IGS.

Note that there are several important differences involved in implementing the new absolute patterns:
* The organization of the calibration information now uses the "ANTEX" format, which is documented at:
  ftp://igscb.jpl.nasa.gov/igscb/station/general/antex13.txt
  The old format did not allow for satellite antenna corrections nor azimuthal variations.
* Absolute PCVs can be reported as functions of azimuth as well as elevation.
* Robotic PCVs are measured down to 0 degrees elevation, whereas the relative PCVs (and absolute PCVs derived from them) usually extend only to 10 degrees.
* Absolute PCVs and phase offsets are reported for individual satellites. The PCV values are the same for all satellites within each block type, which are tabulated in the file:
  ftp://igscb.jpl.nasa.gov/igscb/station/general/rcvr_ant.tab
  However, the z-offsets (in the direction from the satellite center of mass

toward the Earth's center) are satellite-specific.
* The IGS satellite block designations generally match those of the GPS operators, except note that the Block IIR group is divided into IIR-A (first eight satellites) and IIR-B (the next four launches: SVN 47, 59-61). There was apparently a redesign of the antenna array. It is expected that the next launch, of the first "modernized" IIR-M satellite, will start a new IIR group.

Under no circumstances should users mix absolute and relative PCVs! Moreover, absolute PCVs require corrections for both satellites and tracking antennas simultaneously!

Implementation issues for absolute PCVs and handling radomes

Based on the work summarized above, sessions at the IGS 2002 "Towards Real-Time" Workshop, held in Ottawa (8-11 April 2002), and the IGS 2004 Workshop and Symposium, held in Berne (1-5 March 2004), were devoted to issues surrounding implementation of absolute PCVs. Important background information is summarized in the position papers from these two meetings: see Rothacher and Mader [2003] available in:
http://igscb.jpl.nasa.gov/igscb/resource/pubs/02_ott/session_8.pdf
and Schmid et al. [2005a] available in:
http://igscb.jpl.nasa.gov/igscb/resource/pubs/04_rtberne/Session10_1.pdf

The IGS Analysis Centers (ACs) are currently in a test phase of using the absolute antenna PCV corrections in parallel, unofficial solutions.

Associated with adoption of the absolute PCVs, the handling of antenna radomes has also been modified:
* PCVs for antenna + radome pairs will be used, where measured. The effect of radomes was more or less ignored in IGS relative PCVs (some ACs are using the NGS relative antenna+radome calibrations presented in igs_01.pcv). This change can cause apparent station height differences up to several cm. In many cases, suitable radome measurements do not exist; for those, the radome effects will continue to be ignored for the remaining life of that pair.
* Any new antenna + radome pair must have calibration measurements before it can be used in the IGS network.
* Position information for a station not having a calibrated antenna + radome pair should be used with care. Vectors to nearby physical points, including co-located techniques, can have errors up to several cm. Replacement of antenna equipment can lead to discontinuities at a similar level.
* All station operators are urged to avoid using radomes unless absolutely essential. If used in the future, radomes must be of a type suitable for calibration and calibration measurements must be performed before IGS use; see: http://igscb.jpl.nasa.gov/igsnetwork/guidelines/guidelines.html#allstrict

Schedule for IGS changes

If current tests are successful, the IGS plans to implement operationally the absolute antenna PCVs for tracking and satellite antennas on 1 January 2006 [the final date will be decided after the evaluation of the AC parallel tests]. The appropriate ANTEX file will be announced beforehand, but it will be quite similar to igs_05.atx.

Summary of expected effects of IGS PCV changes

* TRF scale -- Because the IGS terrestrial frame products have always been rescaled to match ITRF, there should be minimal impact in this respect except that the unscaled GPS frame solutions should be much closer to ITRF and should be more stable over time [Ge et al., 2005].
* TRF distortions -- The relative positions of the stations within the IGS frame will change, in general. The changes will probably be largest for those stations with calibrated antenna + radome combinations. Because of this, such stations will probably have to be removed from the IGS set of reference frame stations. Smaller shifts will be seen due to using azimuthal PCV corrections in some cases.
* New IGS00 realization -- For the reasons above, the IGb00 realization of ITRF2000 will no longer be suitable. A new version and revised set of reference stations will be needed.
* Troposphere estimates -- Due to the correlations between antenna PCVs and the zenith troposphere delay estimates, the latter values will likely change by noticeable amounts. Biases between GPS estimates and those of VLBI or water vapor radiometers should be considerably reduced [Schmid et al., 2005b].
* Orbits -- Because the scale of the satellite orbits is not very sensitive to the TRF scale (being largely determined through Kepler's 3rd law), there should be no major effects on the satellite orbits. Some positional changes, at the quoted noise level, will likely occur however. (Comment: Some satellites such as PRN28 and PRN03 will be more affected, because they have large Z-offsets from the nominal values. For instance, the MIT absolute model orbits for these satellites are much closer to the current IGS orbits than are the (official) relative model solutions, MIT uses a loose radiation model which allows these offsets to have a large effect due to high correlations.).

* Clocks -- Any effects on satellite or station clocks should probably appear minor compared to the quoted noise levels. However, the systematic effect of the TRF scale change will be inherent in the new clocks.
* Long-term continuity -- A discontinuity should be expected for all IGS product time series on 1 January 2006 (TBC), when the new absolute PCVs are implemented. For this reason (and others), the IGS plans a complete reanalysis of all historic GPS data; see IGS Mail #5174. Only when the reanalysis results are available and incorporated into a future version of ITRF will the fullest level of consistency between frames be achieved.
* Mixing products -- As a general rule, users should avoid mixing results from solutions using different PCV conventions. When mixed results are used, a thorough consideration should be given to possible systematic differences.

Considerations for regional networks

In general, analyses of data from regional networks can probably continue using the relative PCVs with little or no impact, even with IGS orbits fixed. However, this will depend on the size of the network and the effects should be tested empirically.

However, SINEX solutions submitted for combination (e.g. solutions from EUREF, SIRGAS and NAREF which enter into the Regional Network Associate Analysis Center combinations) should all be based on an agreed upon antenna model, ideally the one used for all other IGS official products.

On the other hand, precise point positioning (PPP) results using IGS products will not be self-consistent, before and after the PCV change, due to the inherent shift in TRF scale.

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