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RESEARCH ARTICLE

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New global positioning system reference station in Brazil

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Abstract Co-located very long baseline interferometry (VLBI) and global positioning system (GPS) reference stations were installed near Fortaleza, Brazil, in 1993. Both have been important in the realization and maintenance of the International Terrestrial Reference Frame. A new-generation GPS system was installed in 2005 to replace the original station. Experience gained in the prior 12 years was used to improve the design of the GPS antenna mount. Preliminary indications are greatly improved data quality from the new station. Simultaneous observations from the nearly half-year of overlapping operation have been used to determine the local tie between the new and old GPS reference points to about 1 mm accuracy. This can be used to update the 1993 survey tie between the original GPS and the VLBI points, although there are questions about the accuracy of that measurement based on a comparison with space geodetic data. A test of removing the conical radome over the old GPS antenna indicates that it has biased the station height by about 16 mm downward, which probably accounts for most of the previous survey discrepancy.

Keywords GPS · Antennas · Radomes · ITRF · Reference frames · Co-location ties

Background

In 1989, the US National Oceanic and Atmospheric Administration (NOAA) initiated a project, together with the University of Sao Paulo, the Brazilian Instituto Nacional de Pesquisas (INPE), and Universidade Presbiteriana Mackenzie (Sao Paulo), to build a very long baseline interferometry (VLBI) radio observatory near Fortaleza, Brazil. The site is situated on the northeast coast of the country near latitude 3°52′39″S and longitude 38°25′32″W. This location is near the center of the pre-existing network of geodetic VLBI stations in Europe, eastern North America, South Africa, southern South America, and Antarctica, providing a much improved inter-connection of the global VLBI terrestrial reference frame. In turn, the VLBI frame is an essential component of the multi-technique combined International Terrestrial Reference Frame (ITRF), which also includes contributions from global positioning system (GPS), satellite laser ranging (SLR), and DORIS satellite tracking (Altamimi et al. 2002). The VLBI frame is most important in providing an accurate global scale for the combined frame (together with SLR) as well as the rotational connections to the inertial celestial reference frame, which is realized by the coordinates of a set of extragalactic radio sources observed by VLBI.

A surplus 14.2-m (45-ft.) diameter antenna from the US Naval Observatory (USNO) was moved from Green Bank, West Virginia, in late 1992. Erection of the antenna was completed in early 1993 and outfitting for VLBI operations was finished by the middle of that year. The first full, 24-h observing session began on 6 July 1993. Fortaleza joined a relatively sparse network of VLBI stations in the southern hemisphere, most of which NOAA was instrumental in coordinating, equipping, and supporting operationally for a number of years.

In 1993, shortly before VLBI operations began at Fortaleza, NOAA installed a co-located GPS station, FORT, which has been a part of the International GNSS Service (IGS) network ever since. Unlike most GPS stations, FORT had access to the ultra-stable H-maser frequency standard that is required for VLBI observations. The importance of having an accurate local tie measured between the reference points of the co-located VLBI and GPS systems was recognized from the beginning. This is indispensable for tying together the different technique frames forming the ITRF (Altamimi et al. 2002). There are only about 30 such VLBI-GPS tie sites around the world and only a handful of those have accurate locally surveyed ties (Ray and Altamimi 2005). NOAA personnel led the survey campaign to measure this tie during 11–30 September 1993, with assistance from Brazilian personnel (Glover et al. 1994).

In September 2005, NOAA personnel returned to Fortaleza to install a new, modern GPS station at the site. As described below, it was decided that a new receiver should be installed together with a new antenna and antenna mount design a short distance from the old station. The new station, BRFT, began operating on 6 September 2005. Early geodetic results indicate that the new station is performing very well. As was hoped, the new antenna mount design seems to have helped reduce the effects of pseudorange multipath (and presumably phase multipath) by a large amount. The first 5 months of simultaneous data between FORT and BRFT have been used to determine the local tie between these two GPS reference points with an estimated accuracy of about 1 mm per component. This vector can be used to update the local VLBI–GPS tie, although there are indications that the 1993 tie may be biased (Ray and Altamimi 2005). A new site survey is under consideration.

Original Fortaleza GPS station—FORT

Antenna mount and installation

The FORT monument consists of a standard IBGE (Instituto Brasileiro de Geografia e Estatistica) metal disk star-drilled into the concrete rooftop of the easternmost, one-story control building at the Rádio-Observatório Espacial do Nordeste (ROEN) facility outside Eusébio, Brazil, about 22.7 km southeast of Fortaleza. The reference point is inscribed as SAT92009 and has the IERS DOMES designation 41602M001. It is set about 0.4 m south of the north edge of the building and 0.4 m east of the west edge; there is a 0.7-m high parapet around the north and west sides of the building (Glover et al. 1994). A square aluminum platform, supported on two sides by the parapet, is set above the mark, with an aluminum leg extending down to the roof and horizontal braces on the underside to support the remaining corner. An Allan Osborne Associates (AOA) Dorne Margolin model T chokering antenna was mounted flush to the aluminum sheet, which acted as a backplane, with the preamp extending through an opening and plumbed 64.3 cm above the reference point. The configuration of the FORT antenna, mount, and radome is shown in Fig. 1.

GPS observations began on 13 May 1993. The original antenna was replaced by a similar unit in the same location on 20 March 2000, the only difference being that the low-noise amplifier was retrofitted with an Ashtech unit. A conical radome covered the antenna throughout the history of the station (except for the test described below during the last month of the operation). The radome has never been calibrated for its effect on radio wave propagation. Long-term exposure has visibly altered the appearance of the radome, changing its color from an eggshell tint to a deep burnt orange. The texture of the surface has also roughened and become worn (Fig. 2). The final day of observing by FORT was 8 April 2006, after which the station was permanently decommissioned.

Other equipment

The entire history of observing at FORT has involved just two AOA TurboRogue SNR-8000 receivers, the first being replaced on 11 September 1997. The first receiver (s/n T119) used firmware Version 2.8. The second unit (s/n T149) started with firmware Version 3.2.32.1, which was upgraded to 3.2.32.8 (compliant with GPS week 1024 and year 2000 rollovers) on 28 June 1999. The firmware was upgraded again on 4 March 2002 to Version 3.2.32.11. Prior to that time, the TurboRogues were known to have a problem tracking L2 signals under very

Fig. 1 Photograph, taken during installation in May 1993, showing the configuration of the *FORT* antenna, radome, backplane, and mount

Fig. 2 Photograph showing the *FORT* radome in September 2005. Its color and surface texture have markedly degraded since its installation more than 12 years earlier

active ionospheric conditions using 30-s samples (Zumberge and Kunze 1999). The L2 pseudorange observables became quantized when the ionospheric delay reached 8 m and tracking stopped altogether when the level reached 12 m. This problem was most pronounced for sites at low (e.g., FORT) and high latitudes where ionospheric delays are greatest. Firmware 3.2.32.11 was released to rectify this problem (Moore 2002).

The same Sigma Tau H-maser used with the VLBI system provided the external frequency standard for the GPS receiver. All cables were standard coaxial RG-type.

Data quality and performance

Figure 3 shows a plot of the weekly *N*, *E*, and *U* residuals for FORT from a long-term linear fit of IGS combined terrestrial frame solutions (Ferland 2004). The residuals were generated by Altamimi (personal communication) from a rigorous stacking of the IGS SINEX files for the 6-year period from 28 February 1999 to the end of 2004. The antenna replacement in March 2000 is clearly associated with a discontinuity in the station height, although any offsets in the horizontal components are small. The firmware upgrade in June 1999 had no apparent effect on the data quality, but Version 3.2.32.11 in March 2002 greatly reduced the position formal errors. That occurred because the data yield, which previously suffered under active ionospheric conditions, improved significantly when the L2 tracking problem was resolved.

Annual variations are seen in all the three components of the FORT position, but the amplitudes changed after the 3.2.32.11 firmware upgrade. Beforehand, the annual amplitudes were 2.46 ± 0.26, 2.36 ± 0.69, and 8.34 ± 0.96 mm for *N*, *E*, and *U*, respectively. However, after the upgrade the amplitudes changed to 2.01 ± 0.22, 1.06 ± 0.48, and 4.32 ± 0.79 mm, respectively, a halving of the *E* and *U* components. This behavior strongly suggests that much of the nonlinear variation is technique-related rather than a genuine motion of the site.

New GPS station—BRFT

Antenna mount and installation

The base of the antenna mount consists of a tripod, a bit taller than 1.5 m, near the northeast corner of the same building roof as FORT and about 8.66 m distant. Each of the three legs and couplings are made of high-pressure, thick-wall (schedule 80), corrosion-resistant, type 304/304L stainless steel. The legs are 1.25-in. size (1.660-in. outer diameter) threaded pipe in 60-in. lengths. Each 4-in. end piece of each leg has been cut at a 10° bias, rotated 180°, and welded back into the place to create the tripod arrangement. The legs are welded to threaded couplers each of which is mounted and welded into an 8-in. round top stainless steel plate, which is 0.75-in. thick. The legs have been bolted into the concrete rooftop and then each footing has been encased in concrete. Figure 4 shows the installed mount structure. The cost of materials was about $745 and the cost of machining and welding to form the tripod design was about $575 (not including final on-site assembly and welding).

Extending through the center of the 8-in. head plate and slightly above it is a 4-in. segment of a 1.25-in. pipe welded into place to support a "Design 3" SCIGN leveling mount, as shown and documented by University NAVSTAR Consortium (UNAVCO) at their Web site www.unavco.org. After precise leveling and orientation, the mount was welded into place. Figure 5 shows a close-up view of the tripod top, leveling mount, and Leica LEIAT504 (s/n 868) chokering antenna (no radome). A permanent dimpled reference point is positioned in the center of the SCIGN mount 8.3 mm below its top mounting surface, against which the base of the antenna preamplifier sits. In principle, it should be possible to replace antenna units of similar types without changing the eccentricity or causing unintended height shifts.

Rationale for installation changes

Despite the care taken in positioning the original FORT antenna with respect to local geodetic control marks, it has since become clear that the effects of the uncalibrated radome and aluminum backplane could reasonably cause significant errors in its apparent location as

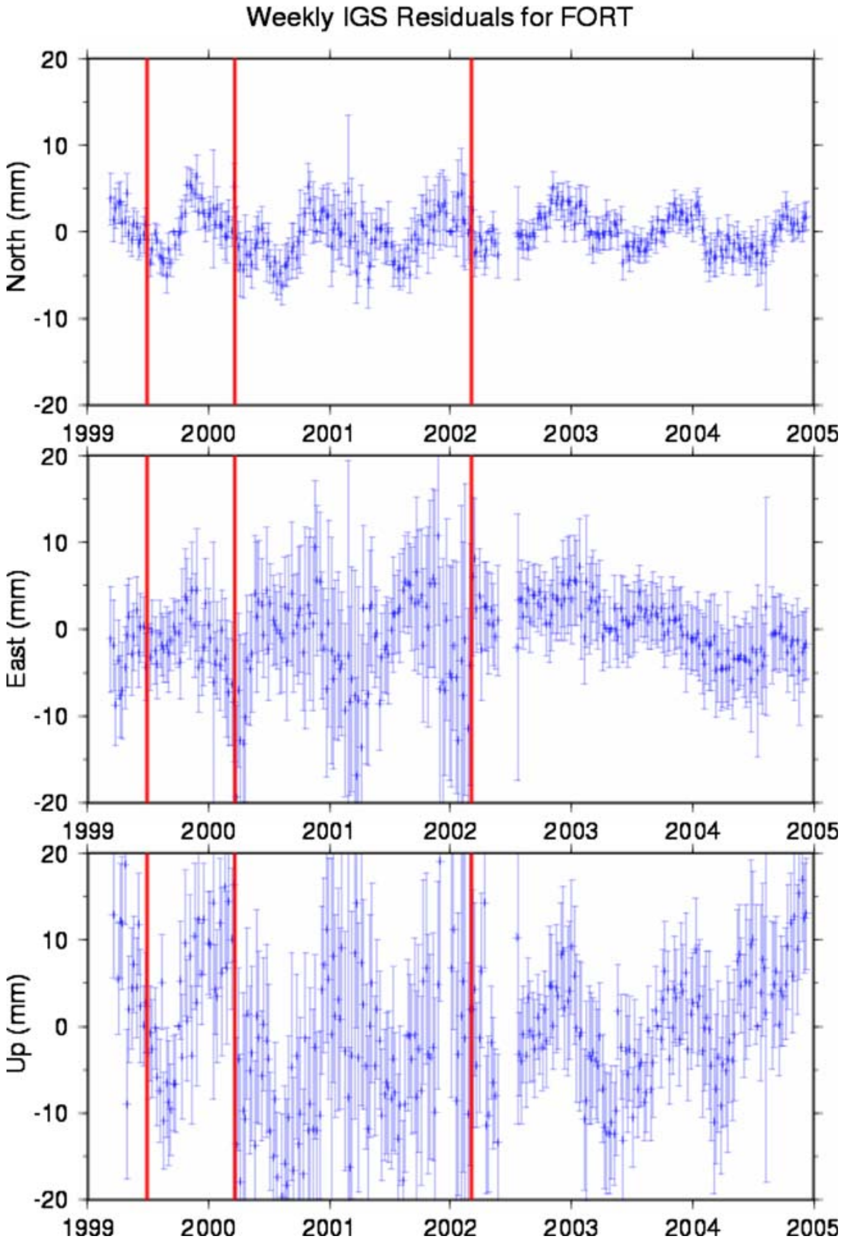

Fig. 3 The nonlinear topocentric residuals for weekly *FORT* positions are plotted for a 6-year period. The residuals were generated from a rigorous stacking of *IGS* combined *SINEX* solutions by Altamimi (personal communication). *Vertical lines* mark configuration changes: update of receive firmware to Version 3.2.32.8 on 28 June 1999; swap of chokering antenna on 20 March 2000; new firmware Version 3.2.32.11 on 4 March 2002

determined from GPS data. For this reason, it was deemed unlikely to replace the old system with modern equipment (and no radome) without causing a position shift. So an entirely new, independent installation was chosen in order to permit an overlap of observations and the empirical determination of an accurate GPS offset tie between the two systems.

On the basis of the studies of Elósegui et al. (1995), demonstrating the serious multipath problems that can be caused by near-field reflecting surfaces (see also Byun et al. 2002), the BRFT mount was specifically designed to place the antenna well above any extended background reflecting surfaces. The 8-in. tripod head plate is an unavoidable compromise, but it is only about half the width of the 37.94-cm (14.94-in.) chokering assembly.

The metal tripod mount does raise some concern over position changes due to thermal expansion. The typical expansion coefficient for steel (and many other substances) is around $1–2 \times 10^{-5}$. For the BRFT structure, that would imply a thermal sensitivity of about 0.03 mm/K. At the equatorial Fortaleza site, the annual mean temperature variation is only a few degrees, so the amplitude of any thermal expansion effect should be no more than a fraction of a millimeter.

Fig. 4 This view of the BRFT antenna and mount, taken during its installation in September 2005, is towards north. The steel tripod stands about 1.5 m tall up to the bottom connection plate

Fig. 5 Photograph showing a close-up view of the tripod top, SCIGN leveling mount, and Leica LEIAT504 chokering antenna

Thermal expansion of the building itself should be a larger effect.

Other equipment

The BRFT receiver is a Leica GRX1200PRO model (s/n 452719), which receives a 5-MHz frequency reference from the local Sigma Tau H-maser. A single 36-m segment of Andrew LDF4-50 heliax cable connects the antenna to the receiver. This cable type was chosen due to its very low thermal sensitivity (about 0.044 ps/K/m), about an order of magnitude less than RG-type cables. Observations began on 6 September 2005.

Table 1 The configurations and data metrics for the two GPS stations at Fortaleza

Aspect	FORT	BRFT
DOMES no.	41602M001	41602M002
Install date	13 May 1993	6 September 2005
Monument	Dimpled steel disk on roof of one-story building	Dimpled point within SCIGN leveling mount
Mount	Aluminum backplane braced to roof and parapet	1.5-m tall steel tripod on roof of one-story building
Antenna	AOAD/M_TA_NGS	LEIAT504
Radome	Conical (uncalibrated)	None
Hgt offset	0.643 m	0.0083 m
Receiver	ROGUE SNR-8000	LEICA GRX1200PRO
Firmware	3.2.32.11	2.12
Clock	External Sigma Tau H-maser	External Sigma Tau H-maser
No. overlap days	111	154
Mean no. obs	18610	26970
Mean deleted	2507.9	1.4
Mean % usable	67.1	98.9
Mean MP1 (m)	0.33	0.28
Mean MP2 (m)	0.98	0.34
Mean slips	49.6	61.5

Both stations are located near different corners on the rooftop of a one-story control building at the ROEN facility. The period of data overlap considered here is 17 September 2005 to 18 February 2006. Mean daily TEQC statistics are computed over this period and shown in the bottom seven lines (assuming an elevation cutoff of 10°)

Comparisons of data quality

TEQC metrics

Table 1 compares salient attributes of the FORT and BRFT systems, together with mean data quality statistics computed over the period 17 September 2005 to 18 February 2006. The TEQC utility from UNAVCO (Estey and Meertens 1999) was used for the quality assessment. There were 111 complete 24-h RINEX files for FORT and 154 files for BRFT considered in the comparison. The poorer recovery of FORT data was due to greater communication problems with the old TurboRogue receiver. About 45% more usable (complete dual-frequency) observations are produced on average each day by the new BRFT Leica receiver as the FORT TurboRogue (using an elevation angle cutoff of 10° for both). This can be ascribed to the greater number of channels of the Leica (12) compared with the TurboRogue (8) and the much lower poor data rejection rate of the former. Interestingly, the number of phase cycle slips per day is somewhat larger for the Leica receiver. These occur almost exclusively below 15° elevation and might be caused by the two tall radio towers on the site (see Fig. 5 for a view of one tower in the background). It is unlikely that the multipath RMS statistics, MP1 and MP2, are comparable for the two receiver types as they extract different modulations (L1C/A for BRFT vs. P1 for FORT), and probably use distinct internal pseudorange smoothing algorithms.

Clock stability

Figure 6 compares the GPS receiver clock behaviors for FORT and BRFT during GPS week 1349 (13–19 November 2005). The results are from the Web site of the IGS Clock Products Working Group maintained by K. Senior at https://goby.nrl.navy.mil/IGStime/. The common timescale is that of the IGS Final clock products, and both clocks are shown after separate linear trends have been removed. Apart from an overall quadratic variation of both clocks due to the H-maser itself, the short-term changes of the FORT clock, mostly diurnal, are much larger than for BRFT. Considering the same H-maser source is common to both systems, one reason for the difference in behavior is the very low temperature sensitivity of the BRFT antenna cable. It is also possible that the Leica receiver is inherently less sensitive to temperature changes than the TurboRogue (both are kept in the same room), but this has not been measured. Owing to its greater stability, BRFT typically contributes up to about 2% to the IGS dynamically weighted, combined timescale (Senior et al. 2003), whereas the FORT weight is usually about an order of magnitude smaller. The most stable clocks in the timescale receive weights of about 9 or 10%.

Day-boundary clock discontinuities

The quality of pseudorange observables from stations equipped with H-masers can be sensitively assessed by examining the geodetic clock results. This is possible because the overall clock bias for a given processing arc (usually 24 h) is set by the average of the code data, whereas the higher frequency variations are determined mostly by the carrier phase data. Assuming an average uncertainty of 1 m for code data and 5 min sampling, the formal accuracy of each clock estimate should be around 120 ps. A quantitative test of the actual clock accuracy can be made by comparing clock estimates at the boundaries between adjacent, independent analysis arcs (i.e., at midnight epochs between consecutive days; see Ray and Senior 2005). This is analogous to the classic geodetic repeatability test for a time series of positioning results. The test is only feasible when H-masers are used because the instabilities of lesser frequency standards dominate over the day-boundary jumps caused by code data quality.

Figure 7 plots the time series of day-boundary clock discontinuities for FORT and BRFT considering both the IGS final and rapid clocks; these plots are also from the K. Senior Web site. The RMS of the jumps for FORT is about 500 ps but only about 120 ps for BRFT, which however has far less data. The difference in behaviors is apparent in the time domain plot of Fig. 6. Within the IGS network of about 50 H-maser stations, RMS clock jumps range between about 120 and 1500 ps. This very large dispersion is thought to be caused by the widely variable effects of local long-wavelength (near-

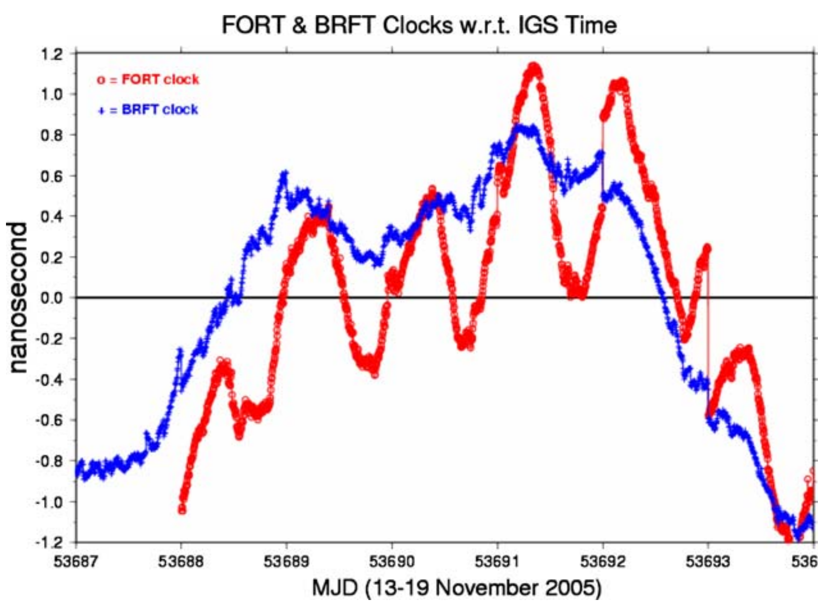

Fig. 6 Variations of the *FORT* (*circles*) and *BRFT* (*crosses*) *GPS* receiver clocks are shown during Modified Julian Dates (*MJD*) 53,687–53,693 (13–19 November 2005), each measured against the *IGS* Final timescale and with a separate linear trend removed. Both receivers are provided with 5 MHz external frequency signals from the same Sigma Tau H-maser

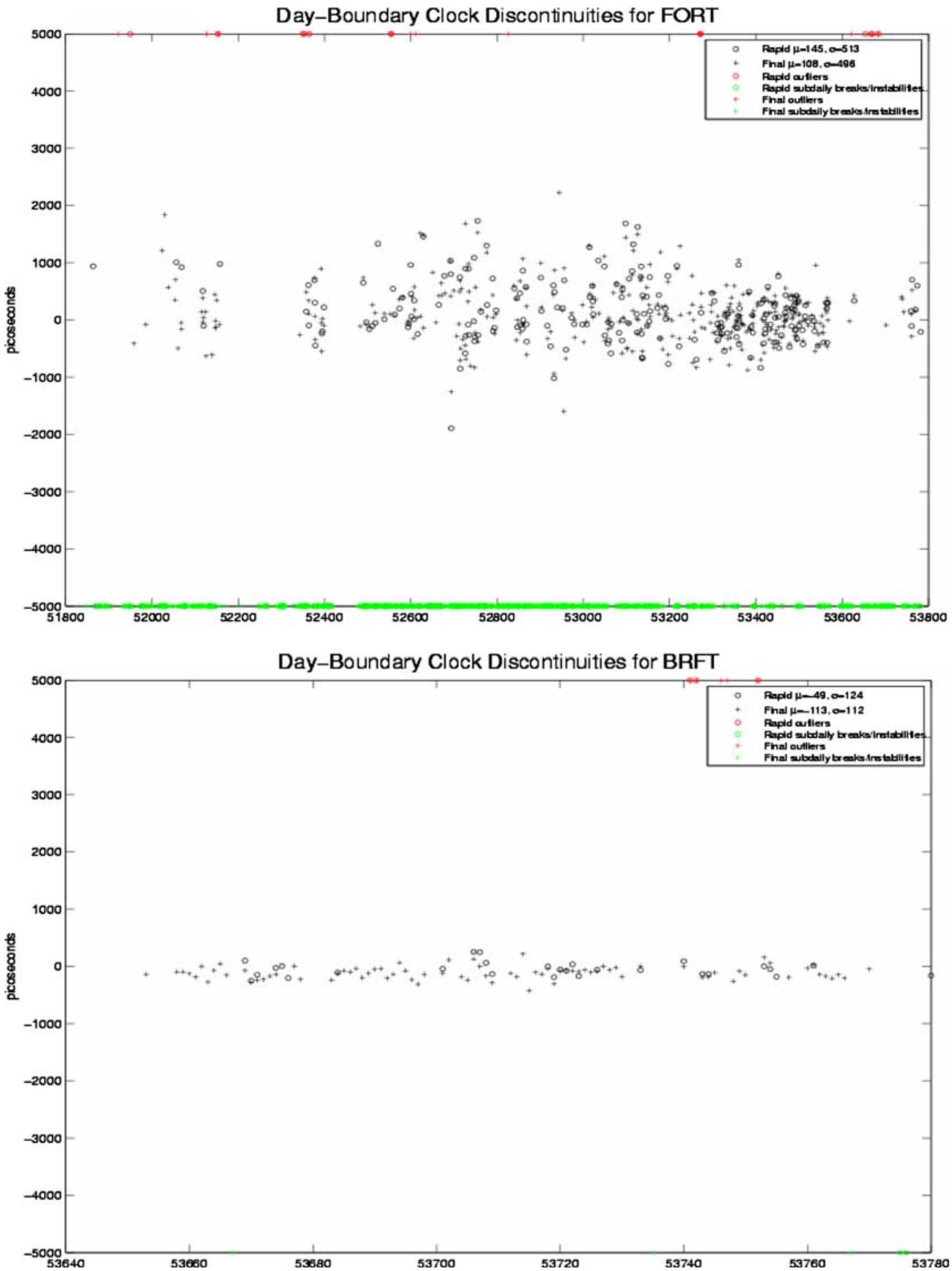

Fig. 7 The discontinuities in clock estimates at day boundaries are plotted for FORT (*top*) and BRFT (*bottom*) as a function of time. Results include both the IGS final and rapid clock products. The *MJD* timescales run from 13 September 2000 to 6 March 2006 for FORT, and from 27 September 2005 to 14 February 2006 for *BRFT*. The *RMS* of the day-boundary clock jumps is about 500 ps for *FORT* and about 120 ps for *BRFT*

field) code multipath, particularly due to close reflections from behind the antenna (Elósegui et al. 1995; Byun et al. 2002). So far, BRFT performs as well as the best long-term IGS station, ONSA (Onsala, Sweden).

The results are consistent with the conclusion that long-wavelength code multipath is unusually low at

BRFT. Presumably, any associated phase multipath is also attenuated; however, that cannot be directly demonstrated as any such bias would be absorbed into the non-clock parameter estimates.

Update of local ties

FORT → BRFT

Using all the available simultaneous 24-h data involving FORT and BRFT between 27 September 2005 and 24 February 2006 (111 days), the vector tie between their reference points has been determined (see Table 2, top half). The weighted mean and RMS are given for each geocentric component. The data analyses used L3 ionosphere-free double-differenced carrier phase data with fixed IGS satellite orbits and fixed phase ambiguities, and were performed with the NGS on-line positioning users service (OPUS) automated system (Mader et al. 2003). One tropospheric bias parameter was adjusted for each daily session. Relative antenna phase center offsets and elevation-dependent variations have been applied in the analysis according to the IGS standard file ftp://www.igscb.jpl.nasa.gov/igscb/station/general/igs_01.pcv. Results were weighted daily by a factor proportional to the number of available data (although this has negligible effect compared to equal weighting). The statistical standard errors for the mean components would be much smaller than 1 mm if all days were treated independently, which is known to be highly optimistic (e.g., Williams et al. 2004). So, formal errors of about 1 mm for each component are recommended as conservative.

Note that better repeatability for the FORT → BRFT tie could be achieved by using single-frequency solutions and not adjusting a relative tropospheric bias (e.g., Ray et al. 2005). However, our greater concern here is to avoid any possibility of bias, relative to global GPS analyses, that would limit our ability to tie the VLBI and GPS frames. The antenna phase calibrations, for instance, do not have the same impact on height determinations when no troposphere offset is adjusted. By considering an ensemble of repeated daily solutions, our approach should yield both high precision and high accuracy.

Rotated to the local topocentric frame, the dX, dY, and dZ tie vector corresponds to the dN, dE, and dU offsets from FORT to BRFT of -0.1841, 8.3713, and 2.2169 m, and a length of 8.6618 m. In other words, the BRFT station is located mostly east and up from FORT. The dX, dY, and dZ scatters rotate to mostly dE scatter (2.7 mm) in the topocentric frame.

BRFT coordinates in IGb00 (ITRF2000) frame

The FORT → BRFT tie vector, together with the published IGb00 geocentric coordinates for FORT (Ferland 2003), can be used to infer the equivalent position of BRFT in the IGb00 frame (aligned to ITRF2000), as shown in Table 2 (bottom half). The IGb00 velocity for BRFT is assumed to be identical to FORT. The formal errors for the BRFT position are those of FORT with 1 mm per component added quadratically. Note that the FORT velocity was relatively poorly determined in IGb00, especially in the X component, which makes propagation to recent epochs a bit problematic. The accuracy of the FORT (and by inference BRFT) position and velocity could be significantly improved using the longer history now available.

GPS → VLBI tie

The importance of having an accurate local tie measured between the reference points of the co-located VLBI and GPS systems was recognized from the very beginning. This is indispensable for relating the technique frames

Table 2 The geocentric vector between the FORT and the BRFT GPS reference points is shown in the upper half below

FORT (41602M001) → BRFT (41602M002) GPS tie				
	dX (m)	dY (m)	dZ (m)	YYY:DOY:Second
Weighted mean	6.9258	5.1913	−0.3336	2005:339:43200
Weighted RMS	0.0022	0.0017	0.0003	
Inferred BRFT (41602M002) coordinates in IGb00 frame				
	X (m)	Y (m)	Z (m)	YYYY:DOY:Second
Coordinates	4985393.5480	−3954993.3971	−428426.8034	1998:001:00000
Uncertainty	0.00413	0.00367	0.00221	
Velocity	−0.001887	−0.003463	0.010888	m/year
Uncertainty	0.001378	0.001189	0.000530	

The tie was determined using 111 days of simultaneous 24-hour data from 27 September 2005 through 24 February 2006. In the bottom half are the inferred coordinates for BRFT in the IGb00 frame, determined using the FORT → BRFT tie together with the published IGb00 geocentric coordinates for FORT. The IGb00 velocity for BRFT is assumed to be identical to FORT. The formal errors for the BRFT position are those of FORT with 1 mm per component added quadratically forming the ITRF. There are only about 30 such VLBI–GPS tie sites around the world and only a handful of those have accurate locally surveyed ties. NOAA personnel, under the direction of W.E. Carter, led the survey campaign to measure this tie during 11–30 September 1993, with assistance from Brazilian colleagues. An NGS report of the survey results was prepared by Glover et al. (1994).

The vector tie reported by Glover et al. (1994) from the FORT GPS to the Fortaleza VLBI reference point is shown in Table 3. The objective of the survey was to yield the highest accuracy tie possible, estimated as 2–3 mm uncertainty. This survey tie, together with the FORT → BRFT GPS tie in Table 2, can be used to infer the tie between the new BRFT GPS and the Fortaleza VLBI reference point: −23.5235, −26.9233, and −45.4711 m for dX, dY, and dZ, respectively. The formal error of this tie is unlikely to be better than about 3 mm per component. Indeed, in a comparison between local ties and the global VLBI and GPS frames, Ray and Altamimi (2005) found a discrepancy for FORT (41602M001) → Fortaleza VLBI (41602S001) of 3.0, 0.6, and 22.7 mm in the dN, dE, and dU local frame. The comparatively large error in dU is probably due, in large measure, to the presence of the uncalibrated conical radome over the FORT antenna (see below). It is well established that such radomes can modify the phase response of the antenna in such a way to cause apparent height offsets up to several centimeters. Consequently, both GPS → VLBI ties should be viewed with caution and the inferred BRFT → VLBI tie above is not recommended for use. A new site survey is under consideration.

Table 3 The geocentric vector between the FORT GPS and Fortaleza VLBI reference points is shown, as reported by Glover et al. (1994)

FORT GPS (41602M001) → Fortaleza VLBI (41602S001) tie			
dX (m)	dY (m)	dZ (m)	YYYY:DOY:Second
−16.5977	−21.7320	−45.8047	1993:263:43200

They estimated an accuracy of 2–3 mm per component. This tie is apparently not consistent with space geodetic data by about 2 cm, a discrepancy, which is probably caused mostly by an apparent height displacement due to the conical radome over the FORT antenna (see the text)

Effect of FORT radome

The FORT antenna + radome will be returned to NGS for future calibration measurements. Hopefully, a comparison of those results with the bare antenna calibrations will clarify the role of radome effects on the local tie. In the meantime, a simple test was performed by removing the FORT radome for its last month of operation, at 14:50 UTC on 27 February 2006.

Data analysis results for 28 February to 8 April 2006 (28 days), after the FORT radome was removed, are shown in Table 4 (top half). Rotated to the local topocentric frame, the vector from FORT (no radome) to BRFT has dN, dE, and dU components of −0.1840, 8.3716, and 2.2011 m, respectively. Comparison of this vector to that in Table 2, and assuming that BRFT is unaffected by the radome removal, gives an apparent shift in the FORT (with radome) to FORT (no radome) dN, dE, and dU position of −0.1, −0.3, and 15.8 mm, respectively. The radome effect, when in place, is nearly purely a downward displacement in apparent position.

Ray and Altamimi (2005) found, in a comparison of global GPS and VLBI networks to local ties, that the Fortaleza tie has a dN, dE, and dU discrepancy of 3.0, 0.6, and 22.7 mm for (GPS → VLBI)$_{\mathrm{space}}$–(GPS → VLBI)$_{\mathrm{tie}}$. As the tie was surveyed to physically accessible points and the space geodetic results are subject to other influences, the radome effect could account for 70% of the vertical discrepancy, reducing it to 6.9 mm. The bottom half of Table 4 gives the recommended tie for the BFRT GPS → Fortaleza VLBI vector, based on the FORT data with no radome and the survey result in Table 3.

Table 4 The geocentric vector between the FORT, after its radome was removed, and the BRFT GPS reference points is shown in the upper half

	dX (m)	dY (m)	dZ (m)	YYYY:DOY:Second
FORT-No Radome (41602M001) → BRFT (41602M002) GPS tie				
Weighted mean	6.9136	5.2013	−0.3324	2006:078:43200
Weighted RMS	0.0021	0.0017	0.00037	
Inferred corrected BRFT GPS (41602M002) → Fortaleza VLBI (41602S001) tie				
	−23.5113	−26.9333	−45.4723	Mixed

The tie was determined using 28 days of simultaneous 24-h data from 28 February 2006 to 8 April 2006. In the bottom half is the inferred tie from BRFT GPS to Fortaleza VLBI based on the survey tie in Table 3 (top) and the FORT → BRFT tie measurement with no radome. This value for the GPS → VLBI tie is recommended

Conclusions

Early results indicate that the new BRFT GPS station performs very well. As was hoped, the new antenna mount design (placed well above any nearby reflecting surface) seems to have reduced the effects of near-field pseudorange multipath (and presumably phase multipath) by a large amount, judging from the very low level of clock discontinuities seen at day boundaries. The performance so far is among the best of any H-maser station in the IGS network.

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