UNITED STATES DEPARTMENT OF COMMERCE
NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE
NATIONAL GEODETIC SURVEY

FOUNDATION CORS PROGRAM
LOCAL SITE SURVEY REPORT
BREWSTER, WASHINGTON, USA

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Dates of Data Collection: August 2018
Date of Report: October 2018

Introduction

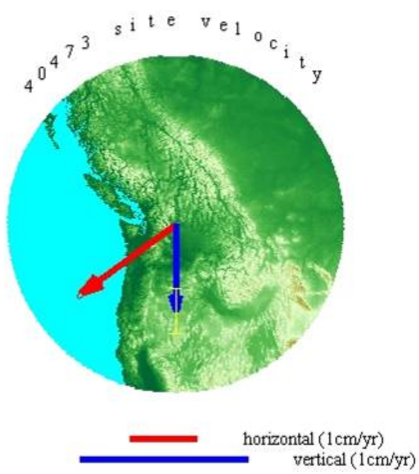
In August 2018, the National Geodetic Survey (NGS) conducted a local tie survey at the International Earth Rotation and Reference Systems Service (IERS) Brewster site, located near Brewster, Washington, USA. The site features co-located space geodetic technique (SGT) instruments that contribute to realizations of the International Terrestrial Reference Frame (ITRF).

Space geodetic techniques at the site include Very Long Baseline Interferometry (VLBI) and Global Navigation Satellite Systems (GNSS). VLBI observations are conducted via a 25-meter radio telescope, operated by the National Radio Astronomy Observatory as part of the Very Long Baseline Array (VLBA). GNSS observations are conducted via a GNSS station, operated by the NASA Jet Propulsion Laboratory (JPL). The GNSS station is an International GNSS Service (IGS) tracking network station and NGS Continuously Operating Reference Station (CORS). It has been identified by NGS as a Foundation CORS.

The primary objective of the survey was to establish high-precision local tie vectors between the VLBI technique 7614, the GNSS technique BREW, and their associated reference marks. Data collection consisted of terrestrial observations with an absolute laser tracker system and GNSS observations with survey-grade instrumentation. The local relationships were aligned to the current International Terrestrial Reference Frame at the epoch date of the survey, ITRF2014 (2018/08/16). This report documents the instrumentation, observations, analysis, and results of the survey.

1 Site description

IERS site name: Brewster
IERS site number: 40473
Country name: United States of America
Surveying institution: National Geodetic Survey
Dates of survey: August 15 – 17, 2018
Longitude: W 119° 41’
Latitude: N 48° 07’
Tectonic plate: North American



SGT Instrument	Name	DOMES#	Description
GNSS	BREW	40473M001	Divot on a SCIGN mount
VLBI	7614	40473S001	25-M VLBA antenna reference point

Table 1 – ITFR site information for space geodetic technique instruments

2 Instrumentation

2.1 Tacheometers, EDMI, theodolites

2.1.1 Description

Leica AT402, S/N 392045 (absolute laser tracker system)
Specifications:
Angular measurement uncertainty of instrument: +/- 0.5”
Combined uncertainty of distance measurement throughout instrument range: +/- 0.014 mm

2.1.2 Calibrations

Leica AT402, S/N 392045
Certified by Leica Geosystem AG Heerbrugg, Switzerland on 2013/08/28.

2.1.3 Auxiliary equipment

Leica ATC meteo-station, S/N D214.00.000.002
Accuracy:
Air temperature: +/- 0.30 C
Pressure: +/- 1 hPa
Relative Humidity: +/- 5%

2.1.4 Analysis software

Terrestrial observations and analysis were conducted with commercially available software Spatial Analyzer (version 2017.08.11_29326) from New River Kinematics. Least squares adjustments were conducted with commercially available software Star*Net (version 9,0,3,6298) from MicroSurvey. Coordinate transformations and SINEX generation were conducted with AXIS software from Geoscience Australia.

2.2 GNSS units

2.2.1 Receivers

Trimble NetR5, P/N: 62800-00, S/Ns: 4624K01583, 4624K01590, 4624K01615
Specifications for Static GPS Surveying:
Horizontal: +/- 5 mm + 0.5 ppm RMS
Vertical: +/- 5 mm + 1 ppm RMS

2.2.2 Antennas

Trimble GPS ground plane antenna, Zephyr Geodetic Model 2, P/N 41249-00, S/Ns: 12545667, 12337624, 12481390

2.2.3 Analysis software

Data processing and analysis were conducted with NGS’s Online Positioning User Service (OPUS) and OPUS Projects. OPUS Projects uses NGS’s Program for Adjustment of GPS Ephemerides (PAGES) software as an underlying multi-baseline processing engine. Star*Net and AXIS were also used in the analysis of GNSS data.

2.3 Leveling

No leveling instrumentation was used in this survey.

2.3.1 Leveling instruments

Not applicable.

2.3.2 Leveling rods

Not applicable.

2.3.3 Checks carried out before measurements

Not applicable.

2.4 Tripods

Wooden surveying tripods with collapsible legs were used to support surveying instrumentation. Fixed-height range poles with attached tripod support legs were used with target reflectors and GNSS antennas. At some stations, a “multipurpose tripod adapter” (MTA) was used with a fixed-height range pole to mount target reflectors and GNSS antennas simultaneously.

Figure 1 – Surveying tripod for instrumentation

Figure 2 – Fixed-height range pole

2.5 Forced centering devices

Target reflectors and GNSS antennas were centered over marks using a fixed-height range pole of known length. Each range pole was verified to be straight and was plumbed over the mark with a precision bubble level.

2.6 Targets, reflectors

Leica Break Resistant 1.5-inch reflector, P/N 576-244
    Centering of Optics: < ± 0.01mm
Leica Reflector Holder 1.5-inch, P/N 577-104
    25mm vertical offset
Brunson Reflector Holder, 1.5THT-.625-11
Leica Tripod Adapter, P/N 575-837

All terrestrial observations were made to Leica 1.5-inch Break Resistant Reflectors, serving as both target and reflector. The reflectors were affixed to the mark forced centering devices using the adapters above.

2.7 Additional instrumentation

No additional instrumentation was used in this survey.

3 Measurement setup

3.1 Ground network

The site has a network of existing ground marks which were recovered in good condition. Non-monumented temporary mark TP01 was established near the center of the project site and used to aid in alignment of the absolute laser tracker measurements. VLBI antenna 7614 does not have an associated physical reference point. The reference point for IGS station BREW is a divot in the GNSS antenna mount that was inaccessible. Both space geodetic techniques were observed indirectly.

Also inaccessible was mark JPL 4019-S, a NASA Jet Propulsion Laboratory steel plate in the top center of a 4.3 meter concrete pillar. The BREW GNSS antenna is attached to a steel mast and bolted on top of JPL 4019-S.

Previous surveys of the site were conducted in 2011 by NGS and in 1993 by Allied Signal Technical Services. The marks included in the current survey are the same as those surveyed in 2011.

3.1.1 Listing

Current Survey	DOMES	IERS 4-char code	Previous Survey Point Name	NGS PID
SGT geometric reference points				
BREW	40473M001	BREW	BREW GPS	DK4090
7614 GRP	40473S001	7614	7614 VLBA	n/a
Ground network marks				
7614 RM1	n/a	n/a	BREWSTER 7614 RM 1	n/a
7614 RM2	n/a	n/a	BREWSTER 7614 RM 2	n/a
BREW ARP	n/a	n/a	n/a	DK4088
BREWSTER A	n/a	n/a	BREWSTER A	n/a
BREWSTER B	n/a	n/a	BREWSTER B	n/a
BREWSTER C	n/a	n/a	BREWSTER C	n/a
NW VLBA	n/a	n/a	NW VLBA 1990	TP1394

Table 2 – Listing of SGT geometric reference marks and ground network marks

Ground network mark descriptions

7614 RM1 is a stainless steel rod, inside of a grease filled sleeve, inside of a protective PVC sleeve, with an aluminum logo cap stamped BREWSTER 7614 RM 1 DEC 1993. The stainless steel rod was previously reported as driven to a depth of 4.0 meters. The grease-filled sleeve depth is unknown. The datum point is the bottom of a dimple near the top center of the rod.

7614 RM2 is a stainless steel rod, inside of a grease filled sleeve, inside of a protective PVC sleeve, with an aluminum logo cap stamped BREWSTER 7614 RM 2 DEC 1993. The stainless steel rod was previously reported as driven to a depth of 3.5 meters. The grease-filled sleeve depth is unknown. The datum point is the bottom of a dimple near the top center of the rod.

BREW ARP (PID DK4088) is the antenna reference point (ARP) of the GNSS station BREW. The ARP is the center of the bottom of the antenna mount.

BREWSTER A is a NGS horizontal control disk set in the top of a concrete post and stamped BREWSTER A 2010. The datum point is the bottom of a dimple near the center of the disk.

BREWSTER B is a NGS horizontal control disk set in the top of a concrete post and stamped BREWSTER B 2010. The datum point is the bottom of a dimple near the center of the disk.

BREWSTER C is a NGS horizontal control disk set in the top of a concrete post and stamped BREWSTER C 2010. The datum point is the bottom of a dimple near the center of the disk.

NW VLBA (PID TP1394) is a NGS horizontal control disk set in the top of a concrete post monument and stamped NW VLBA 1990. This monument is a NGS Federal Base Network station. The datum point is the bottom of a dimple near the center of the disk.

3.1.2 Map of network

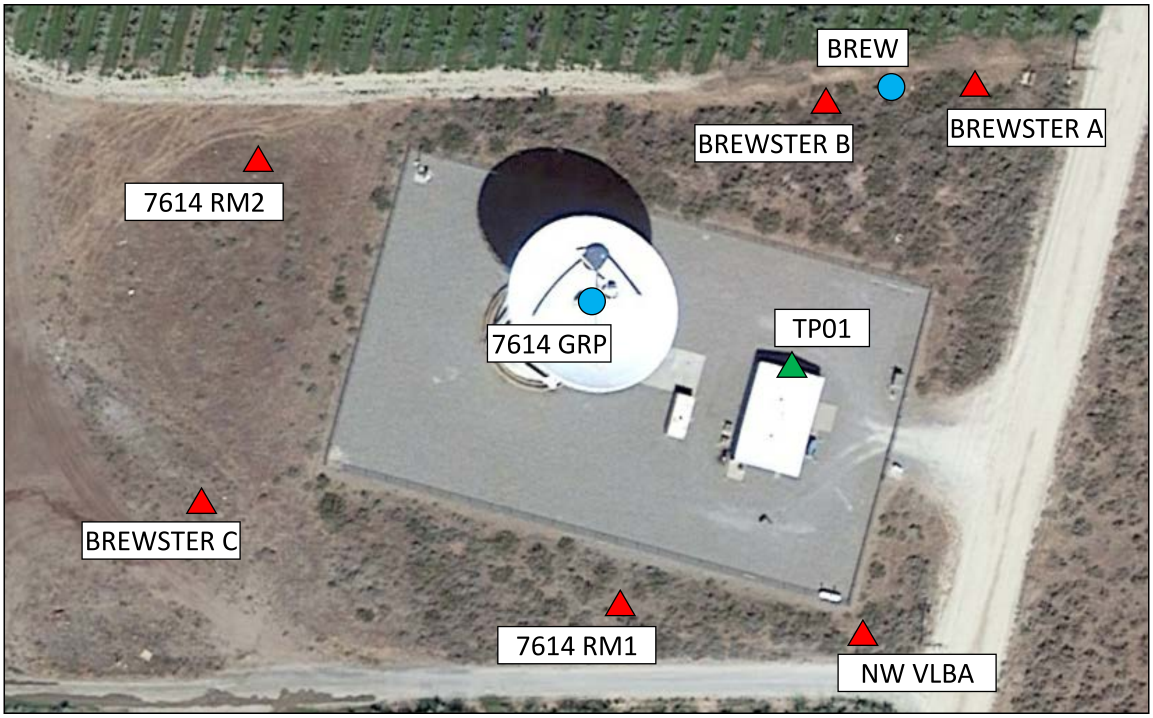


Figure 3

3.2 Representation of technique reference points

3.2.1 VLBI

7614

The VLBI technique is a radio telescope with a 25-meter dish antenna. The instrument's geometric reference point (GRP), also known as the conventional reference point, invariant point, or system reference point, is an intangible point in space. Observations are referenced to this point, about which the azimuth and elevation axes rotate.

For the VLBI technique, the GRP is a theoretical point at the intersection of the azimuth axis and a line mutually perpendicular to the azimuth and elevation axes. An indirect approach was used to determine the GRP in the survey.

Figure 4

3.2.2 SLR

This space geodetic technique was not represented at the site at the time of survey.

3.2.3 GNSS

BREW

Figure 5

The GNSS technique is an IGS tracking station and NGS CORS. The antenna type at the time of survey was an Ashtech choke ring antenna (part number 701945-02 Rev C, IGS antenna code ASH701945C_M, serial number CR620013703). The antenna identifiers matched those in the IGS site log. The GNSS antenna is attached to a SCIGN mount atop a 1.5-meter steel mast with a steel bottom plate bolted to a JPL steel marker plate (mark JPL 4019-S). The JPL plate is set in the top center of a 4.3-meter concrete pillar buried to a depth of 3.7 meters.

The GNSS reference point is a divot in the SCIGN mount. The IGS site log reports eccentricities from the mark to the antenna reference point (ARP) of 0.0083 m Up, 0.0 m North, 0.0 m East. The antenna was not removed this survey and the eccentricities were not able to be verified. The antenna radome was removed for survey observations with approval from NASA JPL. An indirect approach was used to determine the GNSS reference point in the survey.

At the time of writing, the IGS site log is available online.
http://www.igs.org/igsnetwork/network_by_site.php?site=brew00usa

3.2.4 DORIS

This space geodetic technique was not represented at the site at the time of survey.

4 Observations

4.1 Terrestrial survey

The terrestrial survey was completed using an absolute laser tracker system. The instrument measured horizontal angles, vertical angles, and distances to retro-reflector targets which were used to position the marks and techniques.

As part of the observation routine, all angle and distance measurements to ground marks were observed a minimum of three times. Double centering of the instrument was incorporated, measuring in both instrument faces. Meteorological data was observed and atmospheric corrections were applied to all measurements at the time of data collection.

Spatial Analyzer software was used for recording observations and to perform field-level data quality checks for all laser tracker measurements. Star*Net software was used to combine and adjust all observations. A complete list of adjusted observations is available in Star*Net output file ***Brewster2018.lst***.

A diagram of the surveyed network stations is provided.

Vertical offsets of terrestrial observation stations (units in meters)

STATION	STAGE 1	STAGE 2	PRISM	TOTAL OFFSET
7614 RM 1 (Day 1) Offset	Range Pole C 1.04248	MTA C, Overall 0.15065	Leica Nest with Prism 0.05498	1.24811
7614 RM 1 (Day 2) Offset	Range Pole C 1.04248	MTA C, Bottom Plate 0.00980	Leica Nest with Prism 0.05498	1.10727
7614 RM 2 Offset	Range Pole B 1.04224	MTA B, Bottom Plate 0.00978	Leica Nest with Prism 0.05498	1.10701
BREW Offset	IGS eccentricity 0.00830	Antenna top of choke ring 0.10060	Leica Nest with Prism 0.05498	0.16388
BREW ARP Offset	ARP to choke ring 0.10060		Leica Nest with Prism 0.05498	0.15558
BREWSTER A Offset	Range Pole A 1.04260	MTA A, Bottom Plate 0.00978	Leica Nest with Prism 0.05498	1.10736
BREWSTER B Offset	Range Pole D 1.04261		Brunson Nest with Prism 0.05258	1.09519
BREWSTER C Offset	Range Pole E 1.04242		Brunson Nest with Prism 0.05258	1.09500
NW VLBA Offset	Range Pole E 1.04242		Brunson Nest with Prism 0.05258	1.09500

Table 3

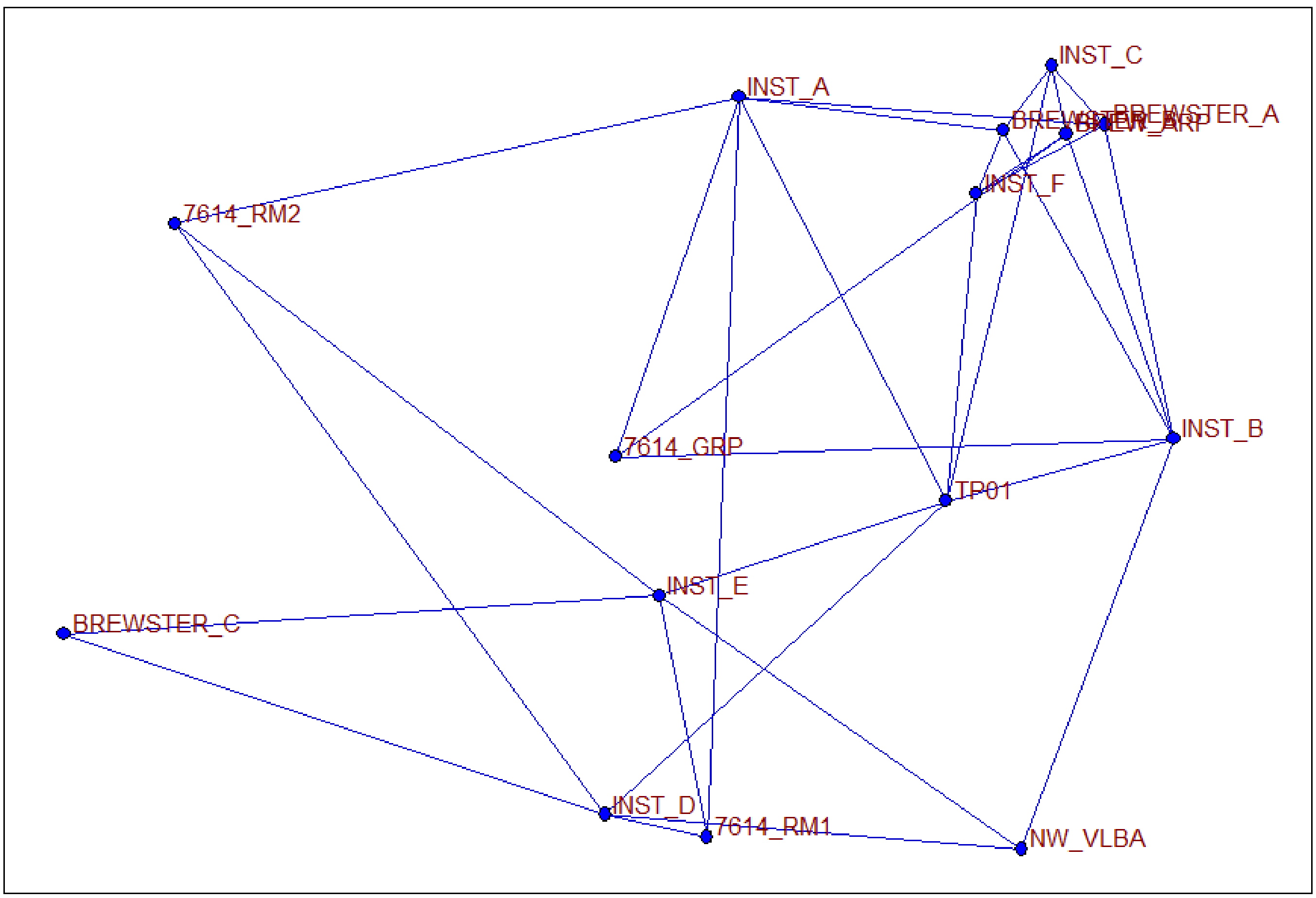


Figure 7 – Terrestrial network diagram

4.2 Leveling

No leveling was conducted for this survey.

4.3 GNSS

GNSS data was collected to generate 3-dimensional IGS2014 vectors between stations at the epoch date of survey, 2018/08/16. Over multiple days, simultaneous long-session (24+ hour) observations were taken at stations 7614 RM1, 7614 RM2, and BREWSTER A. Publicly available observation data was also obtained for CORS in the region. Because the radome was removed for the terrestrial survey, GNSS observation data at BREW was not made available by the operating agency, NASA JPL. Ties from BREW to other stations were sufficiently established by terrestrial means.

GNSS observations were processed with a minimally-constrained, "hub" design emanating from station BREWSTER A. Using the baseline processing engine within NGS's OPUS Projects software, IGS2014 vectors to the network stations and CORS were generated via IGS2014 satellite orbits. For the purpose of this survey, IGS2014 is aligned to ITRF2014 and the two are interchangeable. The resulting GPS vectors were used in a combined network adjustment to align the terrestrial survey to ITRF2014.

Vertical offsets of GNSS observation stations (units in meters)

STATION	STAGE 1	STAGE 2	TOTAL OFFSET
7614 RM 1 Offset	Range Pole C 1.04248	MTA C, Overall 0.15065	1.19313
7614 RM 2 Offset	Range Pole B 1.04224	MTA B, Overall 0.15070	1.19294
BREWSTER A Offset	Range Pole A 1.04260	MTA A, Overall 0.15056	1.19316

Table 4

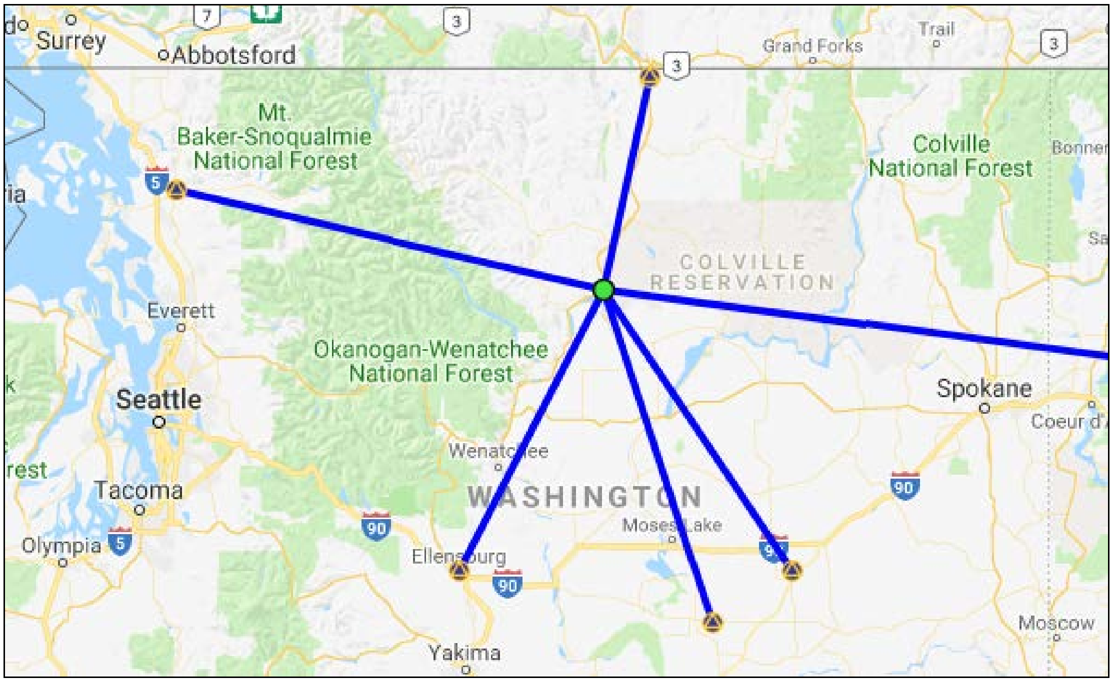


Figure 8 – GNSS network diagram

4.4 General comments

Resection method for terrestrial observations

In the terrestrial survey, the resection principle was employed to measure between network stations indirectly. The ground marks were occupied with the reflector targets mounted on range poles. A temporary point was also established by affixing a short range pole with a reflector target to a stable surface near the center of the project. The instrument did not occupy the marks directly but was instead setup at arbitrary points between the stations. At each instrument occupation, a series of measurements were taken to the surrounding visible stations. By observing common features from different instrument occupations, the relative positions of both the instrument and targets were established.

The resection procedure was chosen to take advantage of the laser tracker's high-precision capabilities and mitigate setup errors. By setting up at arbitrary points rather than occupying the marks, horizontal and vertical centering errors were statistically insignificant. While the vectors between stations were not observed directly, the measurements were precise enough to determine relative positions with sub-millimeter accuracies.

Establishing points via circle-fitting

As noted, determining coordinates of the VLBI geometric reference point (GRP) was achieved using an indirect approach. The "circle fit" theory is described herein. A point, as it revolves about an axis, scribes an arc. The arc defines a circle and a plane simultaneously. The axis can then be defined as it passes through the center of the circle, orthogonal to the plane. By assigning coordinates to the points observed along an arc rotated about an axis, one can assign parameters to the axis relative to an established local coordinate system.

Tracker measurements project coordinates from the local ground network to a target/reflector attached to a geodetic technique instrument as it moves about the instrument's axis, thereby providing the necessary information to locate a single axis. The same procedure must be done for the opposing axis of the instrument in the same local reference frame. The point along the azimuth axis that is orthogonal to the elevation axis is the technique's GRP.

Precise observations involving a single target/reflector secured to the radio telescope, measurements from at least two instrument occupations, and numerous measurements per axis serve to ensure a millimeter level of positional precision is achieved. The VLBI GRP was determined in this manner.

Figures 9, 10 – Target/reflector affixed to VLBI antenna for azimuth and elevation rotation sequences

Coordinates for the IGS station BREW's reference point were also determined using a circle-fitting routine. 3-dimensional measurements were taken to a target/reflector at multiple points along the top of the antenna's choke ring. A sufficient number of points were measured to scribe a circle in space. After accounting for the height of the reflector, the antenna's mechanical offsets, and the IGS reported ARP eccentricity, coordinates were computed to represent the mark BREW. Measurements were taken from three independent locations for redundancy.

Figures 11, 12 - Observations of the choke ring were used to determine GNSS reference point through circle-fitting

5 Data analysis and results

5.1 Terrestrial survey

5.1.1 Analysis software

After data collection, Spatial Analyzer software was used to generate points and lines via circle-fitting, as described above. This allowed for analysis of the VLBI technique's azimuth axis, elevation axis, axial offset, and GRP. Circle-fitting was also used to determine the GNSS technique's reference point.

Terrestrial observations of the ground network and SGTs were brought from Spatial Analyzer to Star*Net software to be combined with the GNSS observations for rigorous least squares adjustment. The combined geodetic adjustment produced coordinates and variance-covariance information for all surveyed features. Adjustment parameters and results are available in Star*Net output file ***Brewster2018.lst***.

5.1.2 Topocentric coordinates and covariance

AXIS was used to compile topocentric coordinate estimates from the combined geodetic adjustment. Using the GNSS observations, the terrestrial survey was aligned to the reference frame ITRF2014 (epoch 2018/08/16). Complete covariance information for all network station is available in AXIS output file ***output.axs***.

Surveyed topocentric coordinates, ITRF2014 (epoch 2018/08/16)						
STATION	***E(m)***	***N(m)***	***U(m)***	***SE(m)***	***SN(m)***	***SU(m)***
BREW	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7614 GRP	-48.0227	-33.3427	11.8732	0.0004	0.0005	0.0002
7614 RM1	-39.0103	-73.5259	-2.1605	0.0007	0.0004	0.0002
7614 RM2	-94.1262	-8.0933	-3.1814	0.0002	0.0009	0.0002
BREW ARP	0.0000	0.0000	0.0083	0.0001	0.0001	0.0000
BREWSTER A	4.0396	0.8974	-1.5783	0.0001	0.0001	0.0001
BREWSTER B	-6.6440	0.4300	-1.4230	0.0001	0.0001	0.0001
BREWSTER C	-106.4567	-51.1498	-2.8708	0.0005	0.0011	0.0003
NW VLBA	-5.8979	-75.3097	-1.9790	0.0007	0.0001	0.0002

Table 5

5.1.3 Correlation matrix

Complete correlation matrix information for all network stations can be found in AXIS output file ***output.axs***.

5.1.4 Reference temperature of radio telescope

The International VLBI Service reports a reference temperature of the radio telescope of 12.4 degrees Celsius. At the time of writing, file ***antenna-info.txt*** is available online.
https://ivscc.gsfc.nasa.gov/program/control_files.html

The support struts of the VLBI telescope are thermally insulated to minimize thermal expansion. No temperature corrections were applied.

5.2 GNSS

5.2.1 Analysis software

NGS's OPUS Projects software was used to process and analyze IGS2014 vectors (considered interchangeable with ITRF2014 vectors) between stations at the epoch date of survey (2018/08/16). The resulting vectors can be found in OPUS Projects output file ***network-final.gfile***.

As noted, Star*Net software was used to combine the terrestrial and GNSS observations in a rigorous least squares adjustment. The combined geodetic adjustment produced coordinates and variance-covariance information for all surveyed features. Adjustment parameters and results are available in Star*Net output file ***Brewster2018.lst***.

5.2.2 Results

AXIS was used to compile geocentric coordinate estimates from the combined geodetic adjustment. Using the GNSS observations, the survey was aligned to the reference frame ITRF2014 (epoch 2018/08/16). Complete covariance information for all network station is available in AXIS output file ***output.axs***.

Surveyed geocentric coordinates, ITRF2014 (epoch 2018/08/16)						
STATION	***X(m)***	***Y(m)***	***Z(m)***	***SX(m)***	***SY(m)***	***SZ(m)***
BREW	-2112007.3476	-3705351.8247	4726827.0452	0.0000	0.0000	0.0000
7614 GRP	-2112065.2885	-3705356.5002	4726813.6332	0.0002	0.0005	0.0004
7614 RM1	-2112067.6385	-3705378.8228	4726776.3635	0.0005	0.0006	0.0003
7614 RM2	-2112091.0557	-3705308.6052	4726819.2744	0.0003	0.0007	0.0006
BREW ARP	-2112007.3503	-3705351.8295	4726827.0514	0.0001	0.0001	0.0001
BREWSTER A	-2112002.9855	-3705352.3293	4726826.4688	0.0001	0.0001	0.0001
BREWSTER B	-2112012.4909	-3705347.4313	4726826.2725	0.0001	0.0001	0.0001
BREWSTER C	-2112117.7485	-3705330.5352	4726790.7688	0.0002	0.0009	0.0007
NW VLBA	-2112039.5888	-3705396.4792	4726775.3081	0.0006	0.0004	0.0001

Table 6 – Coordinate estimates for Brewster network stations, ITRF2014 (epoch 2018/08/16)

The local tie vector, emanating from BREW, is provided below using the coordinates determined this survey.

Surveyed topocentric tie				
STATION	***EAST (m)***	***NORTH (m)***	***UP (m)***	***DIST (m)***
BREW	0.0000	0.0000	0.0000	0.0000
7614 GRP	-48.0227	-33.3427	11.8732	59.6564
Surveyed geocentric tie				
STATION	***X (m)***	***Y (m)***	***Z (m)***	***DIST (m)***
BREW	0.0000	0.0000	0.0000	0.0000
7614 GRP	-57.9409	-4.6755	-13.4120	59.6564

Table 7 – Local tie vector emanating from BREW, ITRF2014 (epoch 2018/08/16)

5.3 Additional parameters

VLBI radio telescope axial offset

Spatial Analyzer software was used to compute the offset distance between the radio telescope's azimuth and elevation axes. The axial offset was computed from four independent observations with an average value of 2.1330 m ± 0.0014 m.

The International VLBI Service reports an axial offset of 2.1346 m, as determined by the 2011 NGS survey. At the time of writing, file ***antenna-info.txt*** is available online.
https://ivscc.gsfc.nasa.gov/program/control_files.html

5.4 Transformations

IGS2014 GNSS vectors (considered interchangeable with ITRF2014 vectors) were generated to Continuously Operating Reference Stations (CORS) in the surrounding region. The vectors were used in a combined geodetic adjustment to align, or transform, the surveyed local ties to ITRF2014 at the epoch date of survey.

5.5 Description of SINEX generation

AXIS software was used to generate a SINEX file with full variance-covariance matrix information. Stations 7614 GRP and BREW are included in SINEX file ***NGSBREW1808GA.snx***.

The following SINEX file naming convention was used.

XXXNNNNYYMMFV.SNX

Where:

- ***XXX*** is a three-character organization designation.
- ***NNNN*** is a four-character site designation.
- ***YY*** is the year of the survey.
- ***MM*** is the month of the survey.
- ***F*** is the frame code (G for global, L for local).
- ***V*** is the file version.

5.6 Discussion of results

A geodetic least squares adjustment of the observations was conducted using Star*Net. The statistical summary from the adjustment is included. For additional details concerning the adjustment, see Star*Net output file ***MonumentPeak.lst***.

```
                Adjustment Statistical Summary
                ==============================

               Iterations              =      4

               Number of Stations      =     22

               Number of Observations  =    367
               Number of Unknowns      =     90
               Number of Redundant Obs =    277

   Observation   Count   Sum Squares        Error
                           of StdRes        Factor
   Coordinates       3         0.000         0.000
    Directions     104        79.755         1.008
     Distances     104        75.134         0.978
       Zeniths     107        82.029         1.008
    Elev Diffs       1         0.000         0.000
    GPS Deltas      48        36.037         0.997

         Total     367       272.956         0.993

         The Chi-Square Test at 5.00% Level Passed
              Lower/Upper Bounds (0.917/1.083)
```

Table 8

Comparison with IERS computed tie

ITRF2014 (epoch 2018/08/16) computed coordinates were obtained from IERS representative Zuheir Altamimi. A comparison of the surveyed tie vector against the computed tie is provided.

IERS geocentric computed coordinates, ITRF2014 (epoch 2018/08/16)				
STATION	*SOL*	*X (m)*	*Y (m)*	*Z (m)*
BREW	-	-2112007.3476	-3705351.8246	4726827.0453
7614 GRP	-	-2112065.2901	-3705356.5049	4726813.6366

Table 9 – IERS computed coordinates, ITRF2014 (epoch 2018/08/16)

Surveyed tie vs. IERS computed tie						
	Topocentric tie discrepancy			Geocentric tie discrepancy		
STATION	*DE (mm)*	*DN (mm)*	*DU (mm)*	*DX (mm)*	*DY (mm)*	*DZ (mm)*
BREW	0.0	0.0	0.0	0.0	0.0	0.0
7614 GRP	-1.0	1.5	-5.7	1.6	4.8	-3.3

Table 10 – Tie discrepancies between surveyed and computed ties

Comparing against the ITRF2014 computed coordinates, the current survey has a maximum tie discrepancy of -5.7 millimeters in the up component.

5.7 Comparison with previous surveys

As a check on the results of the field survey, Star*Net software was used to align the current survey to the NGS 2011 previous survey in ITRF2008 (epoch 2011/07/28). Topocentric tie vector comparisons are provided below for all surveyed stations.

Surveyed geocentric coordinates, ITRF2008 (epoch 2011/07/28)			
STATION	*X (m)*	*Y (m)*	*Z (m)*
BREW	-2112007.2418	-3705351.8254	4726827.1006
7614 GRP	-2112065.1825	-3705356.5019	4726813.6879
7614 RM1	-2112067.5317	-3705378.8247	4726776.4183
7614 RM2	-2112090.9504	-3705308.6072	4726819.3285
BREWSTER A	-2112002.8796	-3705352.3300	4726826.5242
BREWSTER B	-2112012.3851	-3705347.4321	4726826.3277
BREWSTER C	-2112117.6426	-3705330.5378	4726790.8228

Table 11 – Brewster network stations aligned to previous survey, ITRF2008 (epoch 2011/07/28)

Previous survey (NGS 2011) geocentric coordinates, ITRF2008 (epoch 2011/07/28)			
STATION	*X (m)*	*Y (m)*	*Z (m)*
BREW	-2112007.2413	-3705351.8256	4726827.0996
7614 GRP	-2112065.1830	-3705356.5044	4726813.6900
7614 RM1	-2112067.5313	-3705378.8256	4726776.4175
7614 RM2	-2112090.9510	-3705308.6056	4726819.3292
BREWSTER A	-2112002.8772	-3705352.3317	4726826.5246
BREWSTER B	-2112012.3840	-3705347.4332	4726826.3277

BREWSTER C	-2112117.6421	-3705330.5376	4726790.8234

Table 12 – Previous survey coordinates

Surveyed ties vs. Previous survey (NGS 2011) Topocentric tie discrepancies			
STATION	***DE (mm)***	***DN (mm)***	***DU (mm)***
BREW	0.0	0.0	0.0
7614 GRP	-0.2	-0.2	-3.9
7614 RM1	-0.3	0.4	-0.5
7614 RM2	1.8	-1.8	-0.6
BREWSTER A	-2.4	-0.7	-1.2
BREWSTER B	-1.0	-0.2	-1.0
BREWSTER C	0.3	-1.2	-0.8

Table 13 – Tie discrepancies between current survey and previous survey

6 Planning aspects

Physical address of project site:
National Radio Astronomy Observatory
267 Monse River Rd
Brewster, WA 98812

Primary contact for VLBA radio telescope 7614:
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Socorro, NM
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Primary contact for IGS tracking station BREW:
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dstowers@jpl.nasa.gov

Recommendations

Plan observations to the VLBI antenna around weekly maintenance days to minimize the impact on the facility's data collection mission. At the time of the survey, every Wednesday is a maintenance day. Once each month, the technique has two consecutive maintenance days in a week. This would be the optimal week to conduct the site survey. At the time of the survey, the facility was able to accommodate inbound and outbound shipments of equipment.

IGS tracking station BREW is enclosed in a radome, which was required to be removed for the survey. Contact NASA JPL staff before removing the radome.

7 References

7.1 Name of person(s) responsible for observations

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7.3 Location of observation data and results archive

National Geodetic Survey
15351 Office Drive
Woodford, VA 22580
Phone: (540) 373-1243
https://www.ngs.noaa.gov/corbin/iss/

7.4 Works referenced

Fancher, Kendall et al (2012). Local Tie Information Report, IERS Network Site: Brewster, WA. National Geodetic Survey. URL https://www.ngs.noaa.gov/corbin/iss/

International Earth Rotation and Reference System Service. Resolution on the nomenclature of space geodetic reference points and local tie measurements. July 16, 2009.

Nothnagel, Axel (2003). Layout of Local Tie Report. Proceedings of the IERS Workshop on site co-location. Matera, Italy, 23–24 October 2003 (IERS Technical Note No. 33).
https://www.iers.org/IERS/EN/Publications/TechnicalNotes/tn33.html

Poyard, Jean-Claude et al. (2017). IGN best practice for surveying instrument reference points at ITRF co-location sites (IERS Technical Note No. 39).
https://www.iers.org/IERS/EN/Publications/TechnicalNotes/tn39.html

International GNSS Service. http://www.igs.org/

International VLBI Service. https://ivscc.gsfc.nasa.gov/