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

FOUNDATION CORS PROGRAM
LOCAL SITE SURVEY REPORT
LOCAL TIE INFORMATION REPORT
IERS NETWORK SITE: Fort Davis, Texas (USA)

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Dates of Survey: April 1 – April 10, 2026
Date of Report: May 2026

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Introduction

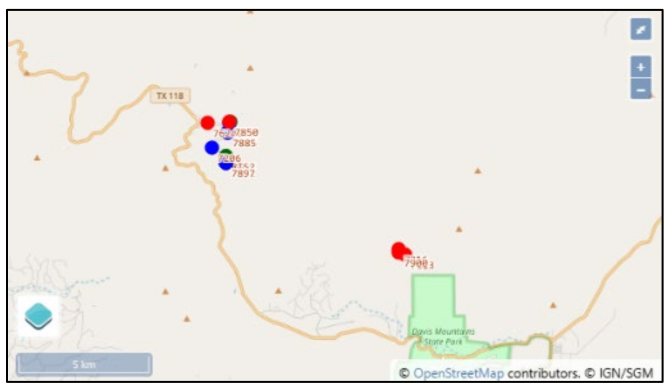
In April 2026, the National Geodetic Survey (NGS) conducted a local tie survey at the McDonald Observatory and the National Radio Astronomy Observatory (NRAO) near Fort Davis, Texas. The site is an International Earth Rotation and Reference Systems Service (IERS) network site designated Fort Davis. The 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 currently include Very Long Baseline Interferometry (VLBI) and Global Navigation Satellite Systems (GNSS). GNSS station MDO1 is an International GNSS Service (IGS) tracking network station and an NGS Continuously Operating Reference Station (CORS). The NRAO facility hosts a 25-meter radio telescope that is a component of the Very Long Baseline Array (VLBA). Since the previous survey, the legacy Satellite Laser Ranging (SLR) instrument was decommissioned, and a new Space Geodesy Satellite Laser Ranging (SGSLR) system is currently being finalized near the MDO1 monument. Additionally, a new VLBI Global Observing System (VGOS) station has been established at the McDonald Observatory. Because the SGSLR is still under construction, NGS will perform a comprehensive local network survey of the McDonald Observatory sub-network at a future date.

The primary objective of this survey was to establish high-precision local tie vectors between the active space geodetic technique instruments and their associated reference marks. Data collection consisted of terrestrial observations with a high-precision total station and survey-grade GNSS instrumentation. The local relationships were aligned to the current International Terrestrial Reference Frame at the epoch date of the survey, ITRF2020 (2026/04/03). This report documents the instrumentation, observations, analysis, and results of the survey.

1. ITRF SITE INFORMATION

IERS site name:	Fort Davis
IERS site number:	40442
Country name:	United States of America
Surveying institution:	National Geodetic Survey
Dates of survey:	April, 2026
Longitude:	W 103° 56’
Latitude:	N 30° 38’
Tectonic plate:	North American



DOMES 40442	Code/ 4-CID	Name	SGT Instrument	Description
S0107	7613	Fort Davis VLBA	VLBA 25-meter	VLBA antenna reference point
M012	MDO1	MDO1	GNSS choke ring antenna	GPS Mark 4011-S

M016	MGO2	MGO2	GNSS Antenna	Reference point of a self-centering SCIGN antenna mount on top of a 1.5 m high, 5 legged deeply drilled braced steel monument.
M017	MGO3	MGO3	GNSS Antenna	Reference point of a self-centering SCIGN antenna mount on top of a 1 m high, 4 legged short drilled braced steel monument
M015	MGO4	MGO4	GNSS Antenna	Reference point of a self-centering SCIGN antenna mount on top of a 1.5 m high, 5 legged deeply drilled braced steel monument
M014	MGO5	MGO5	GNSS Antenna	Reference point of a self-centering SCIGN antenna mount on top of a 1.5 m high, 5 legged deeply drilled braced steel monument
M013	RTS2	RTS2	GNSS Antenna	Reference point of a self-centering SCIGN antenna mount on top of a 1.5 m high, 5 legged deeply drilled braced steel monument
M006	7080	MLRS	SLR Telescope	(Decommissioned) – McDonald Obs.
Pending	TBD	SGSLR	SLR Telescope	(Under Construction) – McDonald Obs.
S018	7624	VLBI	VLBI Antenna	Intersection of axes of a permanent VLBI antenna

Table 1: Space Geodetic Technique (SGT) instruments located at the site

2 Instrumentation

2.1 Tacheometers, EDMI, theodolites

2.1.1 Description

Leica TS60, S/N 886928 (Total Station)
Leica TS60, S/N 897354 (Total Station)
Specifications:
Angular measurement uncertainty of instrument: +/- 0.5”
Combined uncertainty of distance measurement throughout instrument range: +/- 0.6 mm

2.1.2 Calibrations

Leica TS60, S/N 886928
Certified by Leica Geosystems AG Heerbrugg, Switzerland on 2019/09/04.

Leica TS60, S/N 897354
Certified by Leica Geosystems AG Heerbrugg, Switzerland on 2024/09/25.

2.1.3 Auxiliary equipment

Kestrel 5500 Weather Meter, S/N 2830093
Accuracy: Air temperature: +/- 0.50 C
Pressure: +/- 1.5 mbar / Relative Humidity: +/- 2%

2.1.4 Analysis software

Terrestrial observations and analysis were conducted with commercially available software Spatial Analyzer (version 2025.2.0916.2) from New River Kinematics. Least squares adjustments were conducted with commercially available software Star*Net (version 13.0.2.5829) from MicroSurvey. Coordinate transformations and SINEX generation were conducted with AXIS software from Geoscience Australia.

2.2 GNSS units

2.2.1 Receivers

Trimble Alloy, P/N: 109100-10, S/Ns: 5931R40031, 5922R40086, 5931R40027
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 3, P/N 115000.10, S/Ns: 1551008898, 1551008874, 1551014341

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.

2.4 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.

Surveying tripod for instrumentation

Fixed-height range pole

Fixed-height tripod

2.5. Forced-centering devices

Conventional Marks and Tripods

For traditional ground network marks, target reflectors were centered over marks using fixed-height range poles of a calibrated length. To ensure high-precision positioning, each range pole was verified for straightness and precisely plumbed over the mark using a calibrated precision bubble level.

Braced Monuments and SCIGN Mounts

Since the previous survey, new high-stability GNSS monuments have been installed across the sub-network. These include a Deep Drilled braced monument (FDV1), two Shallow Drilled braced monuments (FDV2 and FDV3), and a building-mounted monument (FDVB). The integrated forced-centering device for each of these monuments is a standard SCIGN antenna mount. These SCIGN mounts provided extremely rigid, repeatable forced-centering platforms, allowing the monuments to be directly and interchangeably occupied by the total station, GNSS antennas, and retro-reflectors throughout the main network scheme.

Multi-Technique Adapters (MTA)

To maximize observation efficiency and eliminate centering errors between different measurement phases, custom Multi-Technique Adapters (MTA) designed by the National Geodetic Survey were deployed on the braced monuments. The MTA attaches directly to the SCIGN mount and is engineered to permit the simultaneous collection of terrestrial and GNSS data. The lower tier of the adapter provides standard 5/8" x 11 threads to house a precision retro-reflector, while the upper platform securely elevates a GNSS antenna directly above it on the same vertical axis. This concurrent data collection strategy ensures absolute spatial correlation between the terrestrial and GNSS networks at the braced monuments.

SCIGN Mount at FDV3 with MTA and GNSS Antenna

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

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

2.7 Additional instrumentation

No additional instrumentation was used in this survey.

3 Measurement setups

3.1 Ground network

The site has a network of existing ground marks which were recovered during this campaign. The 25-meter VLBA radio telescope does not have an associated physical mark representing its conventional reference point. Therefore, the space geodetic technique's invariant point (7613) was observed indirectly using a 3D circle-fitting approach based on precise terrestrial observations to targets mounted on the telescope structure.

The reference point for the IGS station MDO1 (McDonald Observatory Site) was physically recovered. As described in the official site log and verified in the field, the monument consists of a 0.457 m diameter stainless steel plate set flush in the center of a 0.762 m diameter concrete monolith that projects 0.5 m above the ground. The specific reference point is defined as the small divot in the top-center of this plate. The GNSS antenna is mounted and centered precisely over this divot using a stainless steel mount secured to the concrete, and is enclosed by a protective radome.

At the Fort Davis NRAO sub-network, the newly installed Deep Drilled and Shallow Drilled braced monuments (FDV1, FDV2, FDV3) and the building-mounted monument (FDVB) were directly occupied for concurrent terrestrial and GNSS data collection using their integrated SCIGN mounts.

A previous local tie survey was conducted by NGS at the Fort Davis site in 2013. The current 2026 survey successfully recovered and included main-scheme legacy marks from that previous survey (such as FDR1, FDR2, FDR3, and JPL4) to provide a rigorous check on the historical consistency and stability of the site's ground marks and space geodetic techniques.

3.1.1 Listing

Current Survey	DOMES	IERS 4-char code	Previous Survey Point Name	NGS PID
Space geodetic technique stations				
Fort Davis VLBA CRP	40442S017	7613	VLBA REF PT (CDP 7613)	--
MCDONALD CORS MONUMENT	40442M012	MDO1	MCDONALD CORS MONUMENT	AF9515
Ground network marks				
FDR1	--	FDV1*	FT. DAVIS VLBA RM1	--
FDR2	--	FDV2*	FT. DAVIS VLBA RM2	--
FDR3	--	FDV3*	FT. DAVIS VLBA RM3	--
JPL 4010 S	--	JPL4	JPL 4010 S	--
FDV1	--	n/a	--	--
FDV2	--	n/a	--	--
FDV3	--	n/a	--	--
FDVB	--	n/a	--	--

Table 2: Listing of SGT stations and ground network marks

* In the 2013 survey, the legacy marks were designated FDV1, FDV2, and FDV3. For the 2026 survey, these legacy marks were renamed FDR1, FDR2, and FDR3 to allow the "FDV" prefix to be assigned to the newly established braced monuments.

Ground network mark descriptions

FT DAVIS VLBA RM 1, FDR1

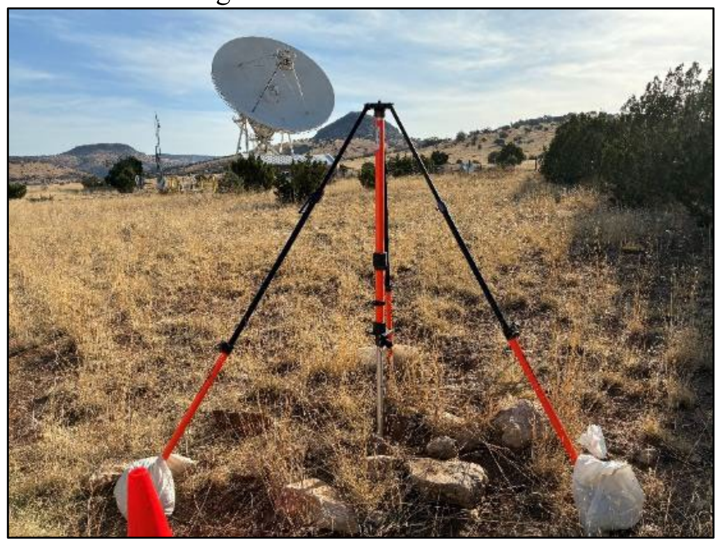
FDR1 is a National Aeronautics and Space Administration (NASA) reference mark established to serve the NRAO VLBA radio telescope. The mark is a punch mark in the center of the rounded top of a 0.012-meter diameter stainless steel rod driven to an unknown depth. It is set approximately 0.3 meters below the ground surface inside a greased 0.025-meter diameter PVC sleeve. The mark and greased sleeve are centered within a larger 0.14-meter diameter PVC pipe held in place with concrete. An aluminum logo cover, set flush with the ground surface, caps the pipe and is stamped "FT. DAVIS VLBA RM1 JAN 90".

FT DAVIS VLBA RM 2, FDR2

FDR2 is a NASA reference mark established to serve the NRAO VLBA radio telescope. The mark is a standard NASA-GSFC brass survey disk set flush and epoxied into bedrock approximately 0.4 meters below the surrounding ground surface. The disk is stamped “FT. DAVIS VLBA RM2 JAN 90”. It is accessed through a 0.14-meter diameter PVC pipe held in place with concrete, which is capped by an aluminum logo cover set flush with the ground surface.

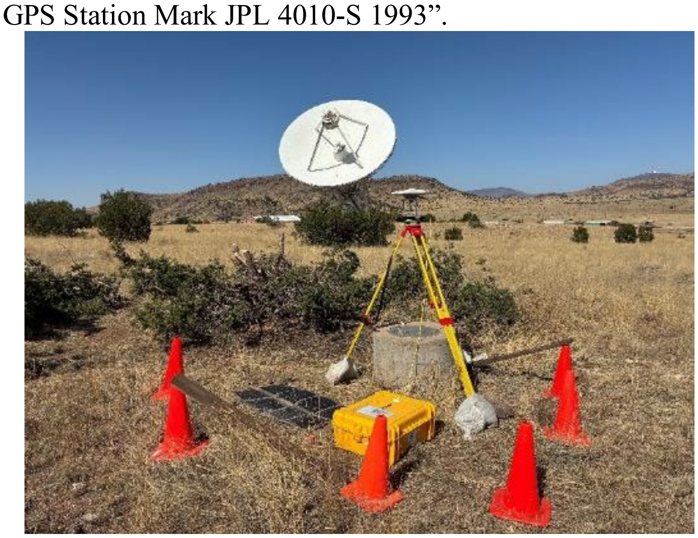
FT DAVIS VLBA RM 3, FDR3

FDR3 is a NASA reference mark established to serve the NRAO VLBA radio telescope. Similar in construction to FDR2, the mark is a standard NASA-GSFC brass survey disk set flush and epoxied into bedrock approximately 0.4 meters below the surrounding ground surface. The disk is stamped “FT. DAVIS VLBA RM3 JAN 90”. It is accessed through a 0.14-meter diameter PVC pipe held in place with concrete, which is capped by an aluminum logo cover set flush with the ground surface.



JPL 4010-S, JPL4

JPL4 is a monument originally established by the Jet Propulsion Laboratory (JPL) to serve as a GNSS station, though it was never utilized as such. The station mark is a punchmark located in the center of an etched triangle on the top of a 0.457-meter diameter stainless steel plate. This plate is set flush in the top of a 0.762-meter diameter concrete monolith that projects 0.5 meters above the ground. The plate is etched with the designation “Fort Davis VLBA Site GPS Station Mark JPL 4010-S 1993”.

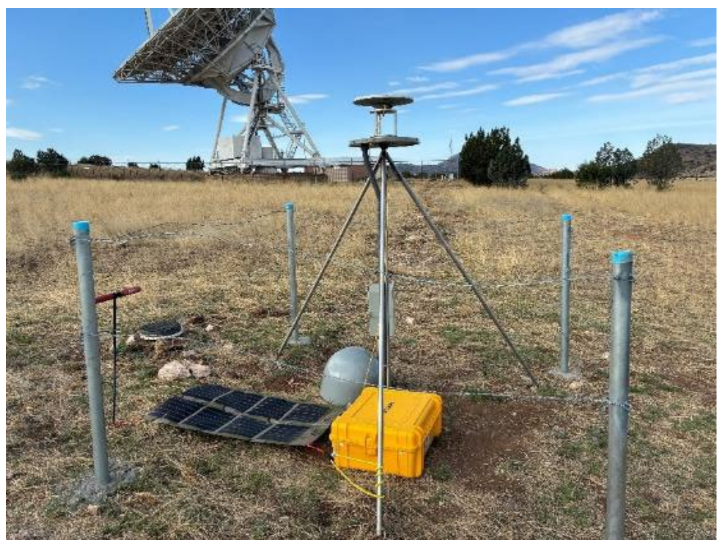


FT DAVIS VLBA 1

FDV1 is a newly established, high-stability Deep Drilled braced monument. The vertical point of reference is typical with the SCIGN mounts; a divot (8.3 mm) below the top plate. It is the reference mark for FDV1 GNSS antenna. The GNSS antenna was installed following observations. The monument is stamped "FT DAVIS VLBA 1 FDV1 2025".

FT DAVIS VLBA 2

FDV2 is a newly established, high-stability Shallow Drilled braced monument. The vertical point of reference is typical with the SCIGN mounts; a divot (8.3 mm) below the top plate. The monument is stamped "FT DAVIS VLBA 2 FDV2 2024".

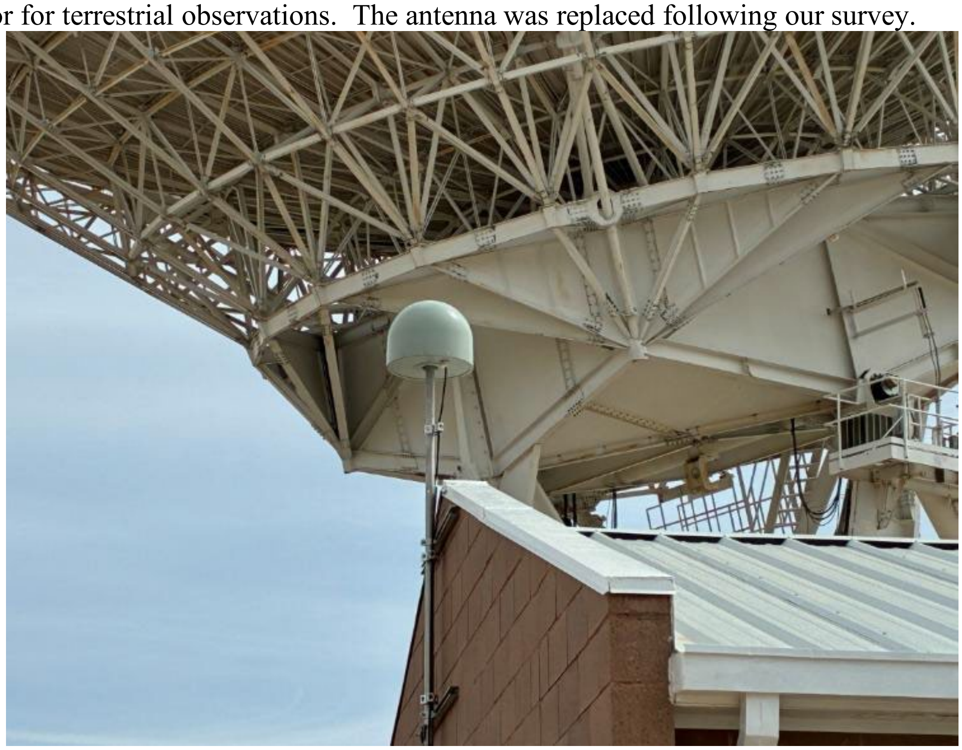


FT DAVIS VLBA 3

FDV3 is a newly established, high-stability Shallow Drilled braced monument. The vertical point of reference is typical with the SCIGN mounts; a divot (8.3 mm) below the top plate. The monument is stamped “FT DAVIS VLBA 3 FDV3 2024”.

FDVB

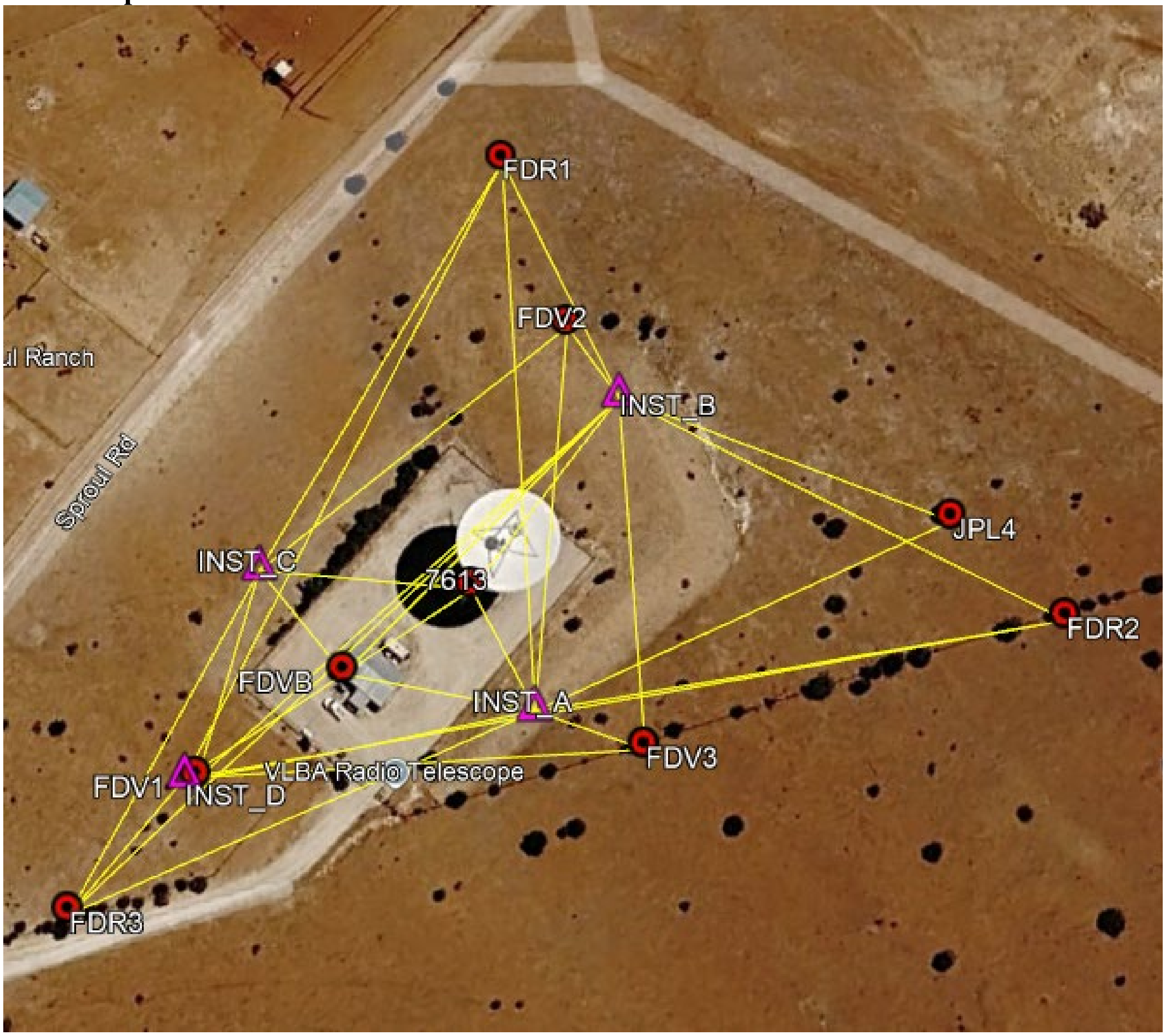
FDVB is a newly established building-mounted monument located within the secure, fenced perimeter of the Fort Davis NRAO VLBA site. The monument consists of a rigid metal pipe securely anchored to the brick wall of the operations building. The mast is topped with an integrated SCIGN antenna mount, which provides precision forced-centering for both terrestrial retro-reflectors and GNSS antennas. During the 2026 survey, the Topcon 02-070801-01 antenna and radome were removed in order to place a retroreflector for terrestrial observations. The antenna was replaced following our survey.



MCDONALD CORS MONUMENT, MDO1

MDO1 serves as an International GNSS Service (IGS) tracking network station and an NGS Continuously Operating Reference Station (CORS). As described in the official site log, the monument consists of a 0.457-meter diameter stainless steel plate set flush in the center of a 0.762-meter diameter concrete monolith that projects 0.5 meters above the surrounding ground. The official reference point is defined as a small divot located in the top-center of the stainless steel plate. The GNSS antenna is centered precisely over this divot using a fixed stainless steel mount secured directly to the concrete. During normal operations, the antenna and mount assembly are enclosed by a protective hemispherical radome.

3.1.2 Map of network

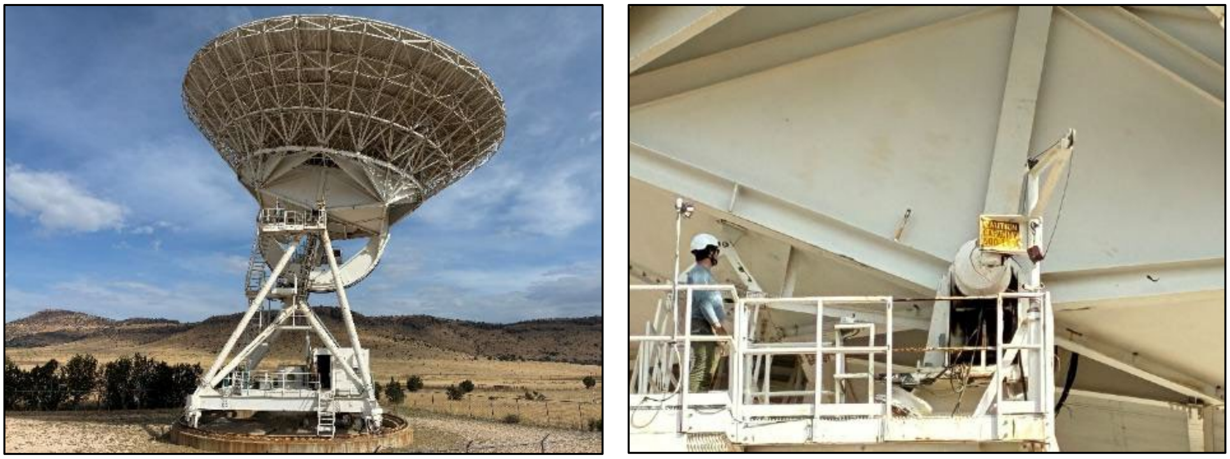


Fort Davis VLBA

3.2 Representation of technique reference points

3.2.1 VLBI

7613 (Fort Davis VLBA) is an active 25-meter VLBI radio telescope operated by the National Radio Astronomy Observatory (NRAO). This instrument is represented by a theoretical point in space: the invariant point (IVP) about which the azimuth and elevation axes rotate. Because the IVP cannot be physically occupied, an indirect approach was used to compute its position. Temporary targets were securely affixed to the telescope structure and tracked with the TS60 total station as they scribed circles about both the azimuth and elevation axes.



7613 and Magnetic Mounted Reflector

7624 is an active VLBI instrument located at the McDonald Observatory sub-network. Because the comprehensive terrestrial survey of the McDonald Observatory sub-network was deferred to a future date, this instrument was not included in the 2026 main scheme and its IVP determination will be documented in that subsequent survey.

3.2.2 SLR

The McDonald Observatory sub-network historically hosted the McDonald Laser Ranging Station (MLRS) and is currently the site of the new Space Geodesy Satellite Laser Ranging (SGSLR) instrument, which is presently being finalized.

Because terrestrial survey operations at the McDonald Observatory sub-network were deferred, neither the decommissioned MLRS nor the SGSLR were targeted or included as part of the 2026 main scheme.

3.2.3 GNSS

The site hosts multiple GNSS technique instruments that contribute to the International Terrestrial Reference System (ITRS), primarily clustered at the McDonald Observatory sub-network.

MDO1 is an active IGS tracking station and NGS CORS. The technique is represented by the antenna reference point (ARP), which is an intangible point typically defined at the base of the GNSS antenna. The antenna is centered over the physical reference divot on a concrete pier and is completely enclosed by a hemispherical radome. While the physical monument was visually recovered by the survey team, it was not observed terrestrially during the 2026 campaign. Its inclusion in the final site coordinate adjustment is based strictly on the GNSS network processing.

MDO1

MGO2, MGO3, MGO4, MGO5, and RTS2 are GNSS stations located at the McDonald Observatory sub-network. Due to the deferral of that sub-network's terrestrial survey, these instruments were not included in the 2026 main scheme.

(Note: JPL4 was originally constructed to serve as a GNSS station, but the system was never implemented. It serves strictly as a ground network reference mark and is detailed in Section 3.1).

4 Observations

4.1 Terrestrial survey

The terrestrial survey of the Fort Davis NRAO sub-network was completed using a Leica TS60 Total Station. This instrument measured high-precision horizontal angles, vertical angles, and slope distances to retro-reflector targets to position the ground marks and determine the space geodetic technique invariant point (IVP) (7613).

Additionally, NGS has developed tools to automate astronomical measurements of deflections of the vertical (DoV) and astronomic azimuths. The Total Station Astrogeodetic Control System (TSACS) is a hardware and software kit that directs a robotic total station to gather imagery of a selected set of stars for geodetic astronomy. NGS has deployed this system extensively to verify geoid undulations and orthometric heights, and utilizes illuminated imaging targets and automated routines for the precise determination of astronomic azimuths.

During the scheduled survey at Fort Davis, NGS implemented TSACS capabilities. The team successfully gathered DoV measurements by imaging up to 25 bright stars over the course of five 15-minute measurement sessions to estimate the deflection of the vertical at the local sub-network.

While the dedicated automated Polaris astronomic azimuth routine encountered a software failure in the field, a contingency methodology was successfully employed. For each DoV observation, TSACS returns a horizontal bias estimate from its observations of 25 bright stars, which captures the difference between the camera-measured star horizontal angles and the azimuth based on the operator’s manual sighting of Polaris. This bias contains the operator’s manual sighting error and the TSACS microcontroller's Polaris ephemeris error. Following each DoV star-imaging session at the Deep Drilled braced monument **FDV1**, direct two-face terrestrial measurements were immediately taken to a retroreflector mounted at the legacy reference mark **FDR1**. Because TSACS sets the horizontal angle of the total station to the azimuth of Polaris at the beginning of each observation, these azimuth measurements capture the astronomic azimuth of the target plus an unknown bias unique to the observation.

During post-processing, TSACS developers were able to estimate precise astronomic azimuths from four of the five observations in this backup dataset. Because the standard analysis index error outputs, which report the mean of residual horizontal star positions for camera frames accepted for vertical measurement, were heavily impacted by outliers in measured horizontal star positions, a correction was computed based on the median values. After multiplying the bias estimates by a factor of two to account for the 60-degree elevation angle of the star observations, these biases were then added to the terrestrial horizontal angle measurements. This methodology yielded a preliminary mean astronomic azimuth of **28° 38' 00.1" ± 1.0"** for four post-DoV shots along the line FDV1-FDR1.

For this report, the astronomic azimuth was used as an independent experimental check rather than as the primary orientation constraint. In the final Star*Net adjustment, the observation was entered as a free, floating observation against the GNSS-derived ITRF network orientation and produced a residual of **8.29 arcseconds**. This comparison indicates that the contingency TSACS-derived azimuth was directionally consistent with the GNSS-oriented network, but the GNSS-aligned adjustment remains the official solution until the backup astronomic azimuth workflow can be further calibrated on a baseline with an independently verified astronomic azimuth using two-face sightings of Polaris. While the backup astronomic azimuths are significantly more repeatable than the GNSS baseline orientation, this technique is presently uncalibrated.

As part of the routine terrestrial observation scheme, all angle and distance measurements to the ground network marks were observed a minimum of three times. Double centering of the instrument was incorporated by measuring in both the direct and reverse instrument faces to eliminate systematic mechanical errors. Meteorological data (temperature, pressure, and relative humidity) was continuously monitored, and atmospheric corrections were applied to all distance measurements at the time of data collection.

To ensure maximum precision and minimize setup errors, the newly established braced monuments (**FDV1, FDV2, FDV3**) and the building monument (**FDVB**) were occupied directly using their integrated SCIGN mounts. Where concurrent GNSS data was required, NGS-designed Multi-Technique Adapters (MTA) were utilized to vertically stack the GNSS antenna and terrestrial retro-reflector on the same physical axis. Legacy marks were occupied using precision retro-reflectors plumbed over the marks using fixed-height range poles.

Spatial Analyzer software was used for recording observations and to perform field-level data quality checks for total station measurements. MicroSurvey Star*Net software was utilized to combine and rigorously adjust all three-dimensional observations. A complete list of the adjusted observations, residuals, and error propagation is available in the Star*Net .lst output file .


DoV observation using TSACS

4.2 Leveling

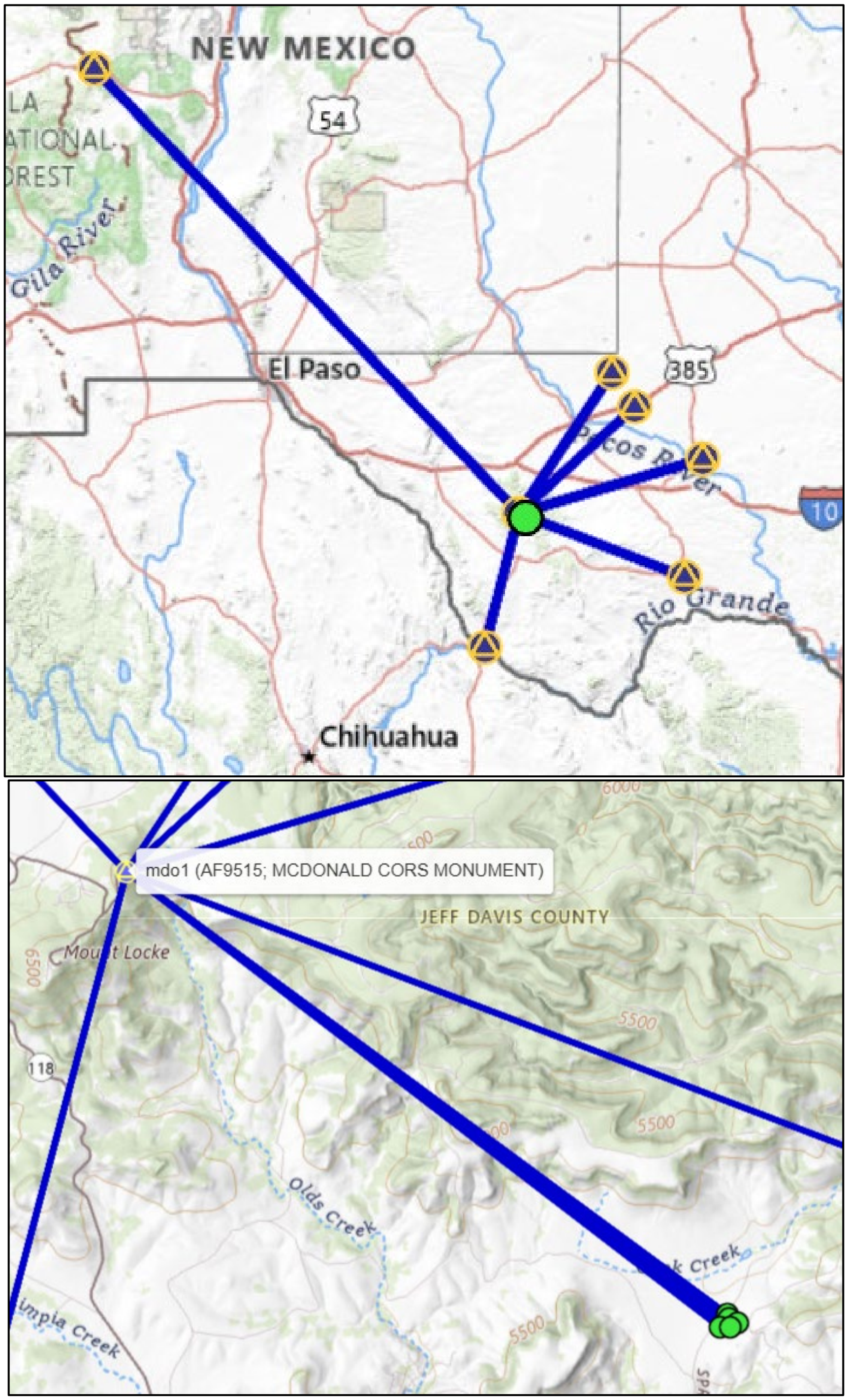
No leveling was conducted for this survey.

4.3 GNSS

GNSS data was collected to generate 3-dimensional ITRF2020 vectors between the local sub-network stations and regional CORS at the epoch date of the survey (2026/04/03). Over a period spanning from March 30, 2026, to April 7, 2026, simultaneous long-session (24-hour) static observations were taken at the newly established braced monuments (FDV1, FDV2, FDV3) and legacy marks (FDR1, JPL4). Publicly available observation data was also obtained for the active MDO1 McDonald CORS and several regional Texas CORS.

The GNSS observations were processed with a minimally constrained, "hub" design emanating from the active MDO1 tracking station. Using the Program for Adjustment of GPS Ephemerides (PAGES) baseline processing engine within the NGS OPUS Projects software, highly precise ITRF2020 vectors connecting MDO1 to the local Fort Davis NRAO network marks were generated utilizing precise ITRF2020 satellite orbits.

Following the baseline processing, the GPSCOM software module was utilized to execute a rigorous least-squares network adjustment of the GNSS observations. The final combined adjustment generated 85 highly precise GPS vectors spanning 10 observing sessions. The resulting GNSS coordinate solutions and variance-covariance matrices were then integrated directly into the Star*Net combined network adjustment to rigorously align the local terrestrial survey to the ITRF2020 reference frame.



GNSS Network Diagram

4.4 General comments

Due to the physical layout and sightline obstructions around the 25-meter VLBA telescope, the total station did not directly occupy the ground network monuments. Instead, the resection principle (free-stationing) was employed to measure between ground marks indirectly. The total station was set up at four highly stable, arbitrary locations (`INST_A`, `INST_B`, `INST_C`, and `INST_D`). Meanwhile, the ground marks were occupied with reflector targets mounted on the SCIGN mounts of the braced monuments (via Multi-Technique Adapters) or precisely plumbed over legacy marks using fixed-height range poles. At each instrument occupation, a series of measurements were taken to the surrounding visible reflector targets. By observing common targets from these different free-station occupations, the relative positions of both the instrument and the ground targets were rigorously established.

Establishing points via circle-fitting
The coordinates of the VLBA instrument's Invariant Point (IVP) were determined using an indirect approach of 3D circle fitting (Jean-Claude Poyard et al., 2017, p. 27). The "circle-fit" theory is briefly described as follows: A target, as it revolves about an axis, scribes an arc. That arc defines a circle and a plane simultaneously. The mechanical axis can then be mathematically defined as the line that 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 precise spatial parameters to the axis relative to the local ground coordinate system.

During the survey, total station measurements projected coordinates from the local ground network to retro-reflectors temporarily attached to the 25-meter VLBA telescope structure as it moved about its axes, thereby providing the necessary information to locate a single axis in space. The same procedure was performed for the opposing axis of the instrument in the exact same local reference frame. The unique point along the azimuth axis that is orthogonal to the elevation axis represents the VLBA technique's Invariant Point (7613).

Precise observations involving targets secured to the VLBA, combined with measurements taken from multiple instrument occupations (`INST_A` through `INST_D`) and numerous measurements per axis, ensured that a sub-millimeter level of positional precision was achieved for the IVP determination.

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 the 3D circle-fitting routines described in the previous section. This spatial analysis allowed for the precise determination of the 25-meter VLBA technique's azimuth axis, elevation axis, axial offset, and ultimate Invariant Point (IVP). *(Note: Circle-fitting routines for SLR and GNSS techniques were not performed during this campaign due to the deferral of the McDonald Observatory sub-network terrestrial survey).* Terrestrial observations of the ground network marks and the computed VLBA IVP were exported from Spatial Analyzer and imported into MicroSurvey Star*Net software. There, they were combined with the OPUS Projects GNSS vectors for a rigorous, three-dimensional least squares network adjustment. This combined geodetic adjustment produced the final ITRF2020 coordinates and variance-covariance information for all surveyed features. All adjustment parameters, statistical summaries, and positional results are available in the Star*Net **`.lst`** output file.

5.1.2 Thermal Expansion
The reference point of the 25-meter VLBA telescope (7613) is defined by its mechanical axes, which are subject to vertical displacement due to the thermal expansion and contraction of the antenna's concrete pedestal and steel structure. Because geodetic coordinates published in the ITRF are referenced to a

standard temperature (established explicitly as 15.5°C for SGT 7613), terrestrial measurements taken at differing field temperatures must be corrected to account for this structural deformation.

The specific physical dimensions of the Fort Davis 25-meter VLBA antenna (such as the height of the concrete foundation and the steel mount) and their respective material thermal expansion coefficients used to compute these corrections were sourced from the official International VLBI Service for Geodesy and Astrometry (IVS) `antenna-info.txt` file. The current, updated file can be accessed via the https://researchdata.tuwien.at/records/e9axk-3kr82

To ensure maximum rigor in the final adjustment, thermal expansion corrections were calculated for the specific environmental conditions present during the TS60 observations of the VLBA axes. These corrections were applied directly within the MicroSurvey Star*Net `.dat` files as highly precise vertical target height offsets applied to the 7613 Invariant Point (IVP) observations.

As documented in the `FDV101.lst` output file, the specific thermal expansion target height corrections applied during each independent instrument occupation were:

- **INST_A:** -0.00023 m
- **INST_B:** +0.00088 m
- **INST_C:** -0.00005 m
- **INST_D:** +0.00018 m

By applying these sub-millimeter corrections directly to the target heights at the observation level, the Star*Net adjustment properly reduced the VLBA's physical geometry to the 15.5°C reference temperature before generating the final 3-dimensional Cartesian coordinates for the space geodetic technique.

7613 VLBI at Inst_A		
Celsius T0	15.5	Reference temperature (C).
c_foundation	0.000010	Coefficient of expansion of foundation material. Concrete, with 6 hour lag time.
c_pedestal	0.000012	Coefficient of expansion of pedestal/antenna material. Steel, with 2 hour lag time.
h_foundation	0.5	Dimension of foundation (m).
h_pedestal	13.7	Dimension of pedestal (m).
Observed Temperatures		
T_foundation	12.9	Six hours before optical survey observations
T_pedestal	14.2	Two hours before optical survey observations
Calculations	**Δh_total = Δh_foundation + Δh_pedestal**	
Δh_total	**-0.00023**	
7613 VLBI at Inst_B		
Celsius T0	15.5	Reference temperature (C).
c_foundation	0.000010	Coefficient of expansion of foundation material. Concrete, with 6 hour lag time.
c_pedestal	0.000012	Coefficient of expansion of pedestal/antenna material. Steel, with 2 hour lag time.
h_foundation	0.5	Dimension of foundation (m).

h_pedestal	13.7	Dimension of pedestal (m).
Observed Temperatures		
T_foundation	13.3	Six hours before optical survey observations
T_pedestal	20.9	Two hours before optical survey observations
Calculations	**Δh_total = Δh_foundation + Δh_pedestal**	
Δh_total	**0.00088**	

7613 VLBI at Inst_C		
Celsius T0	15.5	Reference temperature (C).
c_foundation	0.000010	Coefficient of expansion of foundation material. Concrete, with 6 hour lag time.
c_pedestal	0.000012	Coefficient of expansion of pedestal/antenna material. Steel, with 2 hour lag time.
h_foundation	0.5	Dimension of foundation (m).
h_pedestal	13.7	Dimension of pedestal (m).
Observed Temperatures		
T_foundation	15.6	Six hours before optical survey observations
T_pedestal	15.2	Two hours before optical survey observations
Calculations	**Δh_total = Δh_foundation + Δh_pedestal**	
Δh_total	**-0.00005**	

7613 VLBI at Inst_D		
Celsius T0	15.5	Reference temperature (C).
c_foundation	0.000010	Coefficient of expansion of foundation material. Concrete, with 6 hour lag time.
c_pedestal	0.000012	Coefficient of expansion of pedestal/antenna material. Steel, with 2 hour lag time.
h_foundation	0.5	Dimension of foundation (m).
h_pedestal	13.7	Dimension of pedestal (m).
Observed Temperatures		
T_foundation	15.5	Six hours before optical survey observations
T_pedestal	16.6	Two hours before optical survey observations
Calculations	**Δh_total = Δh_foundation + Δh_pedestal**	
Δh_total	**0.00018**	

5.1.3 Topocentric coordinates and covariance

The terrestrial survey was aligned to ITRF2020 (epoch date of survey) using the GNSS observations in a combined geodetic adjustment. AXIS software was used to compile topocentric coordinate estimates with station **7613** as the local origin. Complete covariance information for all network stations is available in AXIS .AXS output file.

Surveyed topocentric coordinates, ITRF2020 (epoch 2026/04/03)						
STATION	***E(m)***	***N(m)***	***U(m)***	***SE(m)***	***SN(m)***	***SU(m)***
Space geodetic technique stations						
7613	0.0000	0.0000	0.0000	0.0001	0.0006	0.0005
MDO1	-6726.0204	5045.9668	392.5271	0.0004	0.0006	0.0028
Ground network marks						
FDR1	13.7476	108.5297	-19.1227	0.0006	0.0005	0.0005
FDR2	139.7751	-21.7338	-9.5395	0.0002	0.0002	0.0006
FDR3	-98.2516	-69.0903	-14.8404	0.0004	0.0011	0.0004
FDV1	-67.2153	-39.7732	-12.8286	0.0002	0.0010	0.0004
FDV2	26.8881	64.1257	-15.3170	0.0003	0.0005	0.0004
FDV3	38.3762	-43.0102	-9.7239	0.0003	0.0004	0.0004
FDVB	-31.4906	-17.6439	-9.0565	0.0001	0.0008	0.0004
JPL4	115.2362	5.5599	-11.0210	0.0000	0.0000	0.0000

Table 3 Topocentric Coordinates

5.1.4 Correlation matrix

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

5.2 GNSS

5.2.1 Analysis software

NGS's OPUS Projects software was used to process and analyze ITRF2020 vectors between stations at the epoch date of survey. 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. Adjustment parameters and results are available in Star*Net ***.LST*** output file.

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 ITRF2020 (epoch data of survey). Complete covariance information for all network station is available in AXIS ***.AXS*** output file.

Surveyed geocentric coordinates, ITRF2020 (epoch 2026/04/03)						
STATION	***X (m)***	***Y (m)***	***Z (m)***	***SX (m)***	***SY (m)***	***SZ (m)***
Space geodetic technique stations						
7613	-1324009.4920	-5332181.9465	3231962.3221	0.0002	0.0005	0.0006
MDO1	-1329999.0350	-5328393.3676	3236504.0457	0.0007	0.0023	0.0015
Ground network marks						
FDR1	-1323978.8570	-5332115.6173	3232045.9601	0.0006	0.0004	0.0005
FDR2	-1323874.5272	-5332218.4128	3231938.7606	0.0002	0.0005	0.0003
FDR3	-1324110.2550	-5332180.0449	3231895.3125	0.0003	0.0007	0.0010
FDV1	-1324076.9504	-5332174.7055	3231921.5630	0.0002	0.0006	0.0008
FDV2	-1323972.3457	-5332143.9220	3232009.6928	0.0004	0.0004	0.0004
FDV3	-1323975.5122	-5332204.3452	3231920.3598	0.0002	0.0004	0.0004
FDVB	-1324040.3433	-5332175.5206	3231942.5258	0.0001	0.0005	0.0007
JPL4	-1323894.6840	-5332197.7640	3231961.4901	0.0000	0.0000	0.0000

Table 4: Coordinate estimates for network stations

5.3 Additional parameters

VLBI telescope axial offsets
In theory, the VLBI telescope's azimuth and elevation axes intersect. The survey observations were used with Spatial Analyzer software to determine any offset between the axes.

7613 offset: 2.1342 m +/- 1. mm

For 7613, the International VLBI Service reports an axial offset of 2.1298 m.

At the time of writing, file antenna-info.txt is available online.
https://researchdata.tuwien.at/records/e9axk-3kr82

Previous surveys conducted by NGS reported the following axial offsets:
7613 offset 2008: 2.1324 m

5.4 Transformations

ITRF2020 GNSS vectors were generated to CORS in the surrounding region. The vectors were used in a combined geodetic adjustment to align, or transform, the surveyed local ties to ITRF2020 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. All stations with DOMES numbers are included in SINEX file **NGSFTDV2604GA.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 .LST output file.

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

                Iterations              =      3

                Number of Stations      =     19

                Number of Observations  =    709
                Number of Unknowns      =     81
                Number of Redundant Obs =    628

    Observation   Count   Sum Squares        Error
                            of StdRes        Factor
    Coordinates       3        0.000          0.000
     Directions     163      140.449          0.986
      Distances     165      162.405          1.054
        Zeniths     165      175.355          1.095
     GPS Deltas     213      188.970          1.001

          Total     709      667.179          1.031

          The Chi-Square Test at 5.00% Level Passed
               Lower/Upper Bounds (0.945/1.055)
```

Comparison with IERS computed tie

ITRF2020 (epoch date of survey) computed coordinates were obtained from the IERS. A comparison of the surveyed tie vectors against the computed ties is provided where available.

IERS geocentric computed coordinates, ITRF2020 (epoch 2026/04/03)			
STATION	***X (m)***	***Y (m)***	***Z (m)***
7613	-1324009.4915	-5332181.9403	3231962.3256
MDO1	-1329999.0423	-5328393.3616	3236504.0511

Table 5: IERS computed coordinates

Surveyed tie vs. IERS computed tie			
NGS 2026 geocentric tie discrepancies			
STATION	***X (mm)***	***Y (mm)***	***Z (mm)***
7613	-0.5	-6.2	-3.5
MDO1	7.3	-6.0	-5.4

Table 6: Tie discrepancies between surveyed and computed ties (surveyed minus computed)

Comparing ITRF2020 computed coordinates of SGTs, the current survey has a maximum tie discrepancy of 7.3 millimeters in the X component for MDO1.

5.7 Comparison with previous surveys

As a check on the results of the field survey, AXIS software was used to align the current survey to the NGS 2013 previous survey in ITRF2008 (epoch 2013/02/23). Topocentric tie vector comparisons are provided for all common surveyed stations. Complete coordinate information is available in the included data products.

Surveyed ties vs. Previous survey (NGS 2013)			
Topocentric tie discrepancies			
STATION	***DE (mm)***	***DN (mm)***	***DU (mm)***
7613	0.0	0.0	0.0
FDR1	2.3	-0.3	0.1
FDR2	-0.3	-2.9	-0.4
FDR3	-1.4	2.0	0.0

Table 7: Tie discrepancies between current survey and previous survey (current minus previous)

6 Planning aspects

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Recommendations

Provide NRAO with a full list of contacts, schedule, and description of survey schedule as part of a comprehensive visitor safety plan during the planning phase.

Configure equipment and all personal communication devices to not emit RF interference unless specific times are coordinated ahead of time (e.g. Wi-Fi, cellular, Bluetooth)

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
672 Independence Parkway
Chesapeake, VA 23320
Phone: 202-384-6471

7.4 Works referenced

Fancher, Kendall et al (2013). LOCAL TIE INFORMATION REPORT IERS NETWORK SITE: Fort Davis, Texas (USA)
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Geodetic Astronomy - Ryan A. Hardy, PhD.
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