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

## FOUNDATION CORS PROGRAM
## LOCAL SITE SURVEY REPORT
## GREENBELT, MARYLAND, USA
## ITRF SITE NAME:  WASHINGTON


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Dates of Survey: March 25 – April 5, 2024
Date of Report:  June 2024

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## Introduction

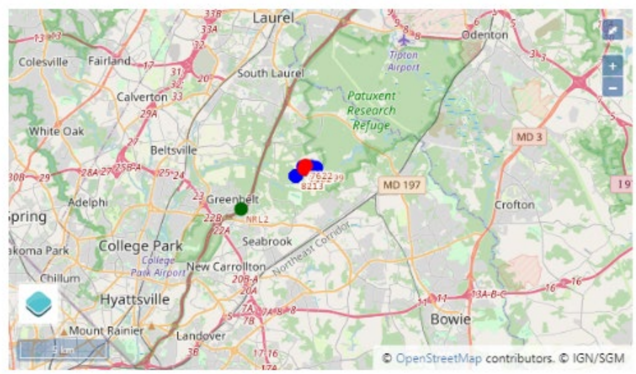
In March 2024, the National Geodetic Survey (NGS) conducted a local tie survey at NASA's Goddard Geophysical and Astronomical Observatory. The observatory is an International Earth Rotation and Reference Systems Service (IERS) site designated Washington located in Greenbelt, Maryland, USA. The site features 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), Global Navigation Satellite Systems (GNSS), Satellite Laser Ranging (SLR), and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS). GNSS station GODE 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 space geodetic technique instruments and their associated reference marks. Data collection consisted of terrestrial observations with an absolute laser tracker system, a 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 (2024/03/30). This report documents the instrumentation, observations, analysis, and results of the survey

## 1. ITRF SITE INFORMATION

IERS site name: Washington
IERS site number: 40451
Country name: United States of America
Surveying institution: National Geodetic Survey
Dates of survey: March-April, 2024
Longitude: W 76° 49'
Latitude: N 39° 01'
Tectonic plate: North American




| DOMES 40451 | Code/ 4-CID | Name | SGT Instrument | Description |
|---|---|---|---|---|
| M105 | 7105 | CDP STATION | MOBLAS-7 GODL | MOBLAS -7 7105-1981 standard NASA disk |
| M123 | GODE | GODDARD GODE JPL | GNSS choke ring | GPS Mark East (JPL 4006) |
| M127 | GODN | GODN | GNSS choke ring antenna | Reference point of a forced centering SCIGN antenna mount on top of a deep-drilled, braced monument |

| | | | | |
|---|---|---|---|---|
| M128 | GODS | GODS | GNSS choke ring antenna | Reference point of a forced centering SCIGN antenna mount on top of a deep-drilled, braced monument |
| S177 | 7622 | VLBI 2010 | VLBI 2010 (12m) | Intersection of axes of a permanent VLBI2010 12m antenna |
| S178 | GRFB | DORIS ANTENNA | DORIS antenna | DORIS antenna ref. pt (Starec type) |
| M113 | 7106 | SLR Mark | 1.2 meter telescope | Intersection of axes of a permanent SLR 1.2m telescope |

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)
Specifications:
Angular measurement uncertainty of instrument: +/- 0.5”
Combined uncertainty of distance measurement throughout instrument range: +/- 0.6 mm

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

### 2.1.2 Calibrations

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

Leica AT402, S/N 392045
Certified by Hexagon Metrology, North Kingstown, RI on 2023/06/23.

### 2.1.3 Auxiliary equipment

Kestrel 5500Weather 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 2022.3.1123.3) from New River Kinematics. Least squares adjustments were conducted with commercially available software Star*Net (version 12.0.3.5251) from MicroSurvey. Coordinate transformations and SINEX generation were conducted with AXIS software from Geoscience Australia.

## 2.2 GNSS units

### 2.2.1 Receivers

Trimble NetR9, P/N: 67668-30, S/Ns: 5835R50374, 5832R50274, 5834R50371

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 115000-00, S/Ns: 6122223769, 6122223766, 6122223925

### 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

Target reflectors 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.

GNSS antenna and the majority of instrument setups were forced-centered on existing monumented piers equipped with a standard 5/8 x 11 threaded stud and leveled using calibrated tribrachs.

## 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. The VLBI antenna 7622 and SGSLR do not have associated physical reference points. The reference point for the IGS station GODE is a small divot in the top-center of a stainless-steel plate that was inaccessible; likewise for the site's other GNSS stations. The VLBI, GNSS and SGSLR space geodetic techniques were observed indirectly. The reference point for the DORIS station GRFB is described as the top and axis of a screw fixed on a stainless steel plate on top of a concrete pillar, however there was no punch mark present. Indirect techniques were performed to determine this axis as well as other reference points associated with this SGT.

A previous survey was conducted by NGS in 2012. The current survey includes marks from the previous survey to provide a check on the consistency of the site's 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** | | | | |
| GODDARD GODE JPL | 40451M123 | GODE | GODE | AA3496 |
| 7622 | 40451S177 | 7622 | 7622 | -- |
| 7105_IVP | -- | -- | MOB7 | -- |
| SGSLR_IVP | -- | -- | SGSLR | -- |
| GODN | 40451M127 | GODN | GODN | DR7484 |
| GODS | 40424M128 | GODS | GODS | DR7487 |
| DORIS ANTENNA 2012 | 40451S178 | GRFB | GRFB | -- |
| 7106 | 40451M113 | 7106 | NOT OBSERVED | -- |
| **Ground network marks** | | | | |
| CAL PIER A | -- | -- | CALA | -- |
| CAL PIER B | -- | -- | CALB | -- |
| CAL PIER D2 | -- | -- | CAL2 | -- |
| GGAO 1 | -- | -- | GGA1 | -- |
| GGAO 2 | -- | -- | GGA2 | -- |
| GGAO VLBI RM PIER A | -- | -- | GGAA | AH5618 |
| GGAO VLBI RM PIER B | -- | - | GGAB | AH5615 |
| GGAO VLBI RM PIER C | -- | -- | GGAC | AH5617 |
| GODDARD 1962 | -- | -- | GODD | JV5872 |
| NGS 1 | -- | -- | NGS1 | -- |
| NGS 2 | -- | -- | NGS2 | -- |
| NGS 3 | -- | -- | NGS3 | -- |
| NORTH GEOS PIER | -- | -- | NORG | JV5895 |
| CAL PIER C | -- | -- | CALC | -- |
| CDP STATION 7105 | 40451M105 | 7105 | 7105 | -- |
| CDP STATION 7125 | 40451M114 | 7125 | 7125 | -- |

Table 2: Listing of SGT stations and ground network marks

Ground network mark descriptions

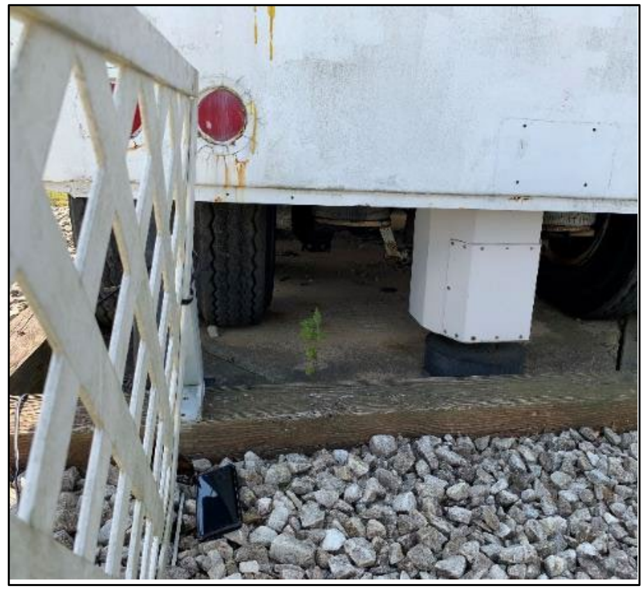
**CAL PIER A, CALA** Defined by the top center of a stainless-steel cup set into the top of a 30-cm (dia.) concrete observing pier. A removable stainless steel adapter rests in the center of this pier with a 5/8" x 11 threaded stud on top. The measured height offset of this adapter is 12.7 mm (0.50 inches).

**CAL PIER B3, CALB** Defined by a self-centering device (stainless-steel plate with 5/8-11 stud) embedded in the top of a 30-cm (dia.) concrete observing pier.

**CAL PIER C**, **CALC** Defined horizontally by the center of a stainless-steel cup set into the top of a 30-cm (dia.) concrete observing pier. A removable stainless steel adapter rests in the center of this pier with a 5/8” x 11 threaded stud on top. The measured height offset of this adapter is 12.7 mm (0.50 inches).

**CAL PIER D2, CAL2** Defined horizontally by a self-centering device (stainless steel plate with 5/8-11 stud) embedded in the top of a 30-cm (dia.) concrete observing pier.

**CDP STATION 7105** Defined horizontally and vertically by a small divot in the top-center of a brass disk stamped MOBLAS STA 7105, set into a drill hole in the concrete pad currently occupied by MOBLAS 7's trailer. It is the reference mark for MOBLAS 7.

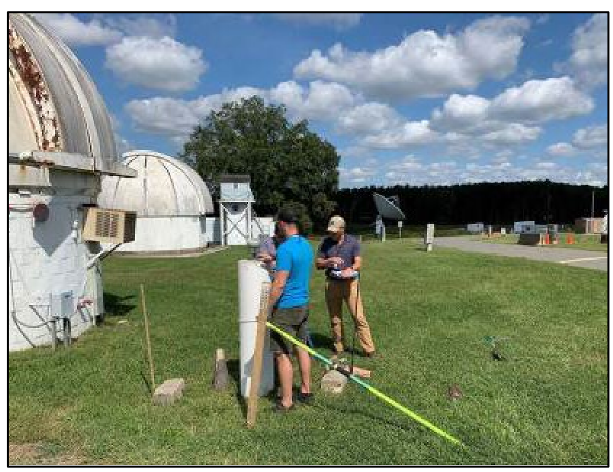



**CDP STATION 7125** Defined horizontally and vertically by a small divot in the top-center of a brass disk stamped GORF-MTLRS 7125 1985, set into a drill hole in the concrete pad occupied by the building housing NGSLR (decommissioned).

**DORIS RM 1** Defined horizontally by a self-centering device (stainless steel plate with 5/8-11 stud) embedded in the top of a 30-cm (dia.) concrete support pier for the DORIS antenna. The vertical point of reference is the top surface of the plate at the base of the stud.

**DORIS RM 2** Defined horizontally by a self-centering device (stainless steel plate with 5/8-11 stud) embedded in the top of a 30-cm (dia.) concrete support pier for the DORIS antenna. The vertical point of reference is the top surface of the stud. It is the reference mark for the DORIS antenna.

**GGAO 1, GGA1** Defined horizontally by a self-centering device (stainless steel plate with 5/8-11 stud) embedded in the top of a 30-cm (dia.) concrete observing pier. The vertical point of reference is the top surface of the plate at the base of the stud. The pier and its buried base, a 60 cm (dia.) x 3 m, is a steel reinforced monolith installed in 2012.

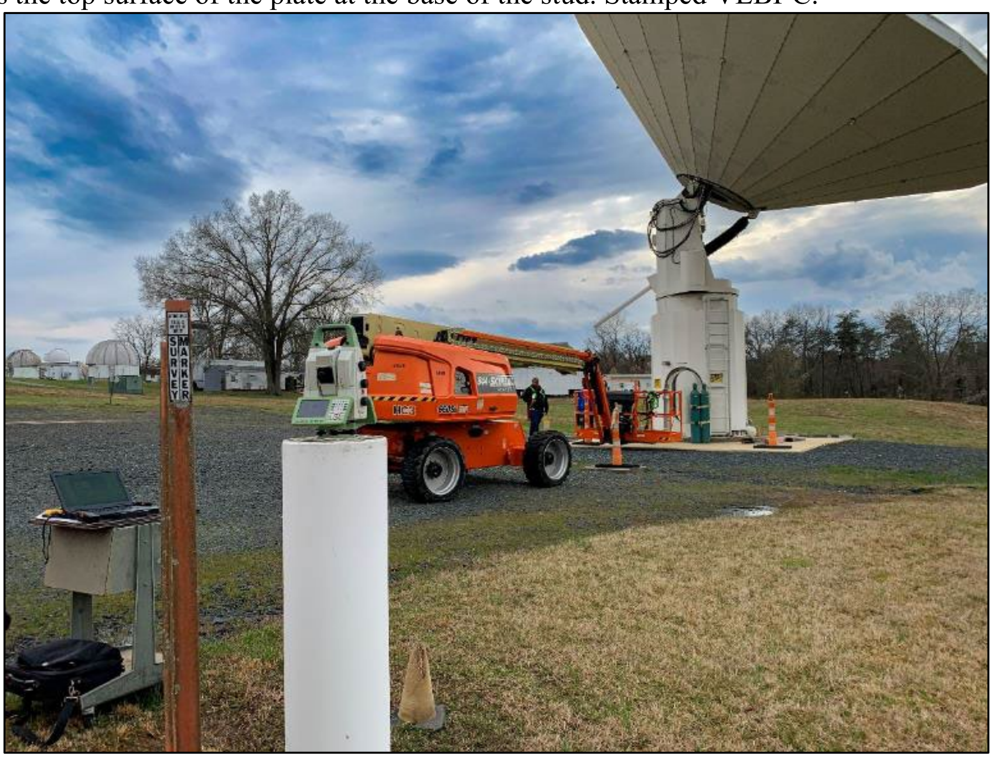


**GGAO 2, GGA2** Defined horizontally by a self-centering device (stainless steel plate with 5/8-11 stud) embedded in the top of a 30-cm (dia.) concrete observing pier. The vertical point of reference is the top surface of the plate at the base of the stud. The pier and its buried base, a 60 cm (dia.) x 3 m, is a steel reinforced monolith.

**GGAO VLBI RM PIER A, GGAA** Defined horizontally by a self-centering device (stainless steel plate with 5/8- 11 stud) embedded in the top of a 30-cm (dia.) concrete observing pier. The vertical point of reference is the top surface of the plate at the base of the stud. Stamped VLBI-A.

**GGAO VLBI RM PIER B, GGAB** Defined horizontally by a self-centering device (stainless steel plate with 5/8- 11 stud) embedded in the top of a 30-cm (dia.) concrete observing pier. The vertical point of reference is the top surface of the plate at the base of the stud. Stamped A, but designated B by previous surveys.

**GGAO VLBI RM PIER C, GGAC** Defined horizontally by a self-centering device (stainless steel plate with 5/8- 11 stud) embedded in the top of a 30-cm (dia.) concrete observing pier. The vertical point of reference is the top surface of the plate at the base of the stud. Stamped VLBI-C.



**GODDARD, GODD** Defined horizontally and vertically by a small divot in the top-center of a brass disk stamped GODDARD 1962, set into the top of a 30-cm (dia.) concrete post recessed 5 cm below ground level.

**GODDARD GODE JPL 4006** Defined horizontally and vertically by a small divot in the top-center of a stainless-steel plate stamped GODDARD GORF EAST FLYNN GPS STATION MARK JPL 4006 1992, set into the top of a 60-cm (dia.) concrete post projecting about 30 cm above ground level.

**GODN** Defined horizontally by a self-centering device (SCIGN GNSS antenna mount) attached to the head block of a deep drilled braced monumtent. 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 GODN GNSS antenna.


**GODS** Defined horizontally by a self-centering device (SCIGN GNSS antenna mount) attached to the head block of a 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 GODS GNSS antenna.

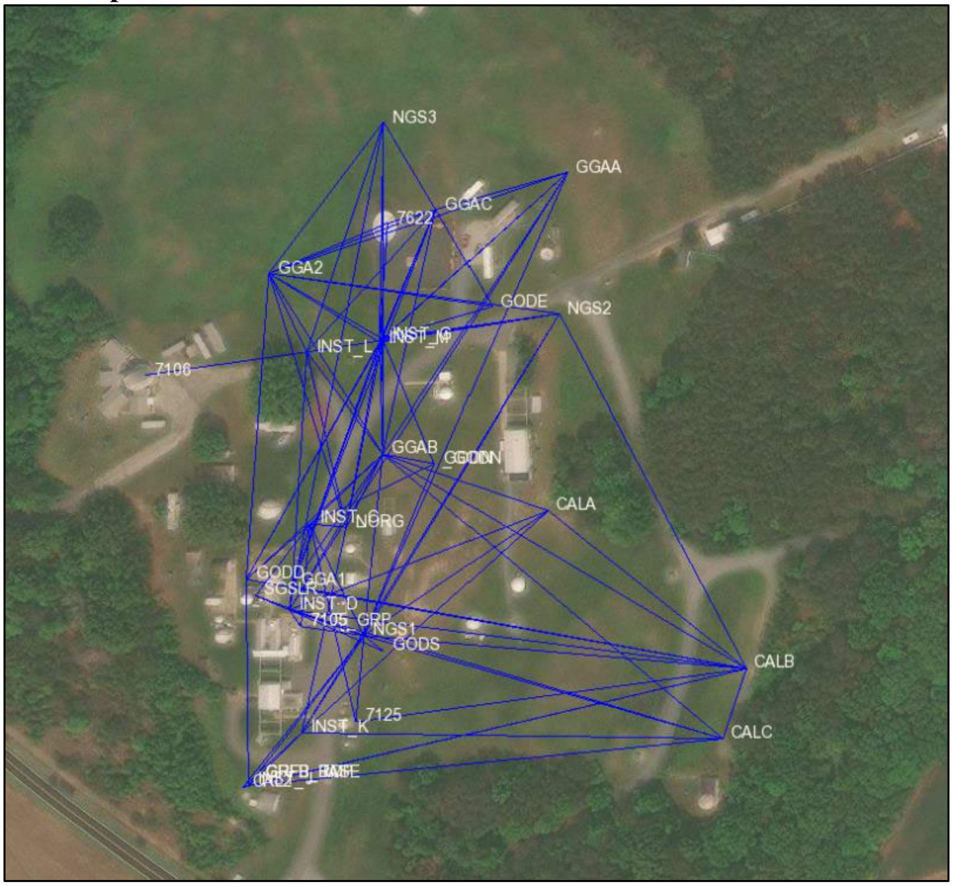
**NGS 1, NGS1** Defined horizontally and vertically by a self-centering device (stainless steel plate with 5/8-11 stud) anchored in the top of a 15-cm (dia.) concrete observing pier encased in PVC pipe. The pier and its buried base, a 45 cm (dia.) x 1 m, is a monolith installed in 2012.


**NGS 2, NGS2** Defined horizontally and vertically by a self-centering device (stainless steel plate with 5/8-11 stud) anchored in the top of a 15-cm (dia.) concrete observing pier encased in PVC pipe. The pier and its buried base, a 45 cm (dia.) x 1 m, is a monolith installed in 2012.

**NGS 3, NGS3** Defined horizontally and vertically by a self-centering device (stainless steel plate with 5/8-11 stud) anchored in the top of a 15-cm (dia.) concrete observing pier encased in PVC pipe. The pier and its buried base, a 45 cm (dia.) x 1 m, is a monolith installed in 2012.

**NORTH GEOS PIER, NORG** Defined horizontally and vertically by a cross etched into the top-center of a brass disk stamped NORTH GEOS PIER, set into the top of a 1-m (on side) triangular concrete monument projecting 50 cm above ground level.
NOTE: An NGS Disk in close proximity stamped, "GODDARD DA" was not included as part of the survey.

### 3.1.2. Map of network




Goddard Geophysical and Astronomical Observatory

## 3.2. Representation of technique reference points

### 3.2.1. VLBI

The site hosts one VLBI instrument. This instrument is represented by a theoretical point in space: the invariant point (IVP) about which the azimuth and elevation axes rotate.

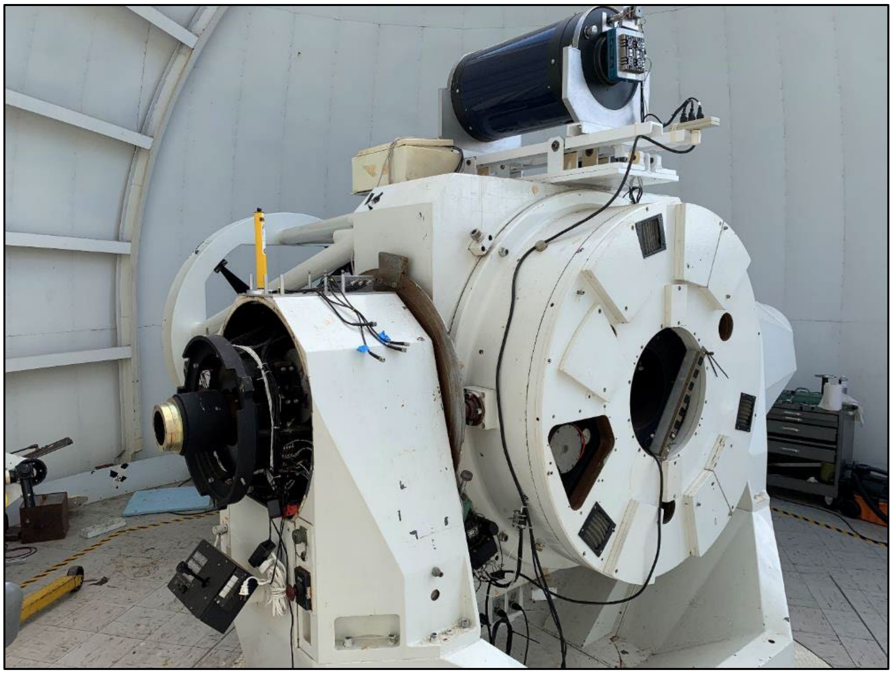
7622 is a VLBI radio telescope with a 12-meter dish operated by NASA


### 3.2.2 SLR

This site hosts 3 SLR instruments. The indirect approach to computing the IVP was used on all units. The electronics on and around the telescopes are very sensitive to rain and must be completely enclosed in advance of inclement weather. A newer instrument was included as part of this survey, known as the "Second Generation" SLR or SGSLR. A 1.2-meter telescope was included as part of the survey, but only during a single instrument setup.

MOBLAS-7 with mounted reflector. Targets were positioned as they scribed circles about the azimuth and elevation axes.

SGSLR with mounted reflector. Targets were positioned as they scribed circles about the azimuth and elevation axes

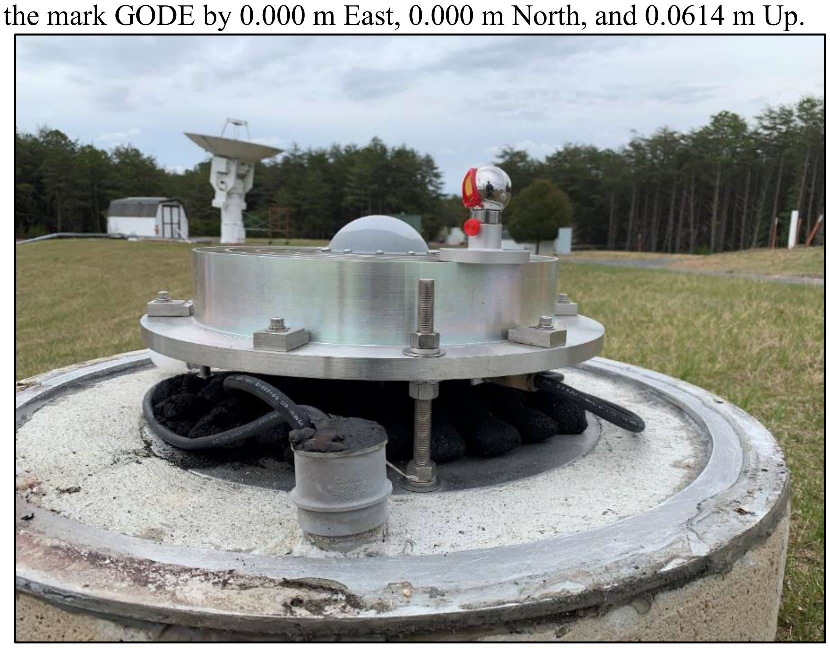


1.2-meter telescope with mounted reflector

### 3.2.3 GNSS

The site hosts four GNSS technique instruments that are maintained by NASA and contribute to the International Terrestrial Reference System. For this survey, only three GNSS antennas were observed: GODE, GODS and GODN. An indirect approach was used to determine positions of the GNSS reference points in the survey, as the antennas were not removed.

***GODE*** is an IGS tracking station. The current GNSS antenna is an AOAD/M_T, serial number 129 with an uncalibrated JPLA radome. Per the IGS station site log, antenna reference point (ARP) is eccentric from the mark GODE by 0.000 m East, 0.000 m North, and 0.0614 m Up.



***GODN*** is an IGS tracking station.  The current GNSS antenna is a TPSCR.G3, serial number 383-0151 with SCIS radome.  Defined horizontally by a self-centering device (SCIGN GNSS antenna mount) attached to the head block of a 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 GODN GNSS antenna.


***GODS*** is a JAVRINGANT_DM  antenna, serial number 02083 with SCIS radome defined horizontally by a self-centering device (SCIGN GNSS antenna mount) attached to the head block of a 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 GODS GNSS antenna.

### 3.2.4 DORIS

***GRFB*** is represented by the antenna reference point (ARP) of the DORIS antenna. The ARP is an intangible point along the vertical axis of the antenna, 390 mm above the antenna base. The center of a red ring around the antenna approximates the ARP position.
An indirect approach was used to determine the position of GRFB. The DORIS system is maintained by France's *Institut National de l'information Géographique et Forestière*.


# 4 Observations

## 4.1 Terrestrial survey

The terrestrial survey was completed using a Leica TS60 Total Station and Leica AT402 Laser Tracker. These instruments measured horizontal angles, vertical angles, and distances to retro-reflector targets 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.

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. NGS has deployed this system in Alaska to verify geoid undulations and orthometric heights and tested it at dozens of locations throughout the United States. In 2022, NGS explored the use of illuminated imaging targets and automated routines for determination of astronomic azimuths.

During the scheduled survey at the GGAO, NGS implemented both TSACS DoV and astronomic azimuth capabilities. NGS gathered a set of 4 DoV measurements at GGAB, with each measurement session imaging up to 25 bright stars over the course of 15 minutes. These images were used to measure their zenith angles and ultimately estimate the deflection of the vertical at that location. A set of 8 astronomic azimuths were gathered and used in the survey, in which the total station repeatedly alternated between imaging Polaris and an illuminated terrestrial target mounted on points in the survey network. Four of these observations were performed with the instrument on GGAB, with GGAA as a target. The other four observations were performed with the instrument on GGAB, with CALB as a target.

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 total station measurements. Star*Net software was used to combine and adjust all observations. A complete list of adjusted observations is available in Star*Net ***.LST*** output file.

DoV observation using TSACS

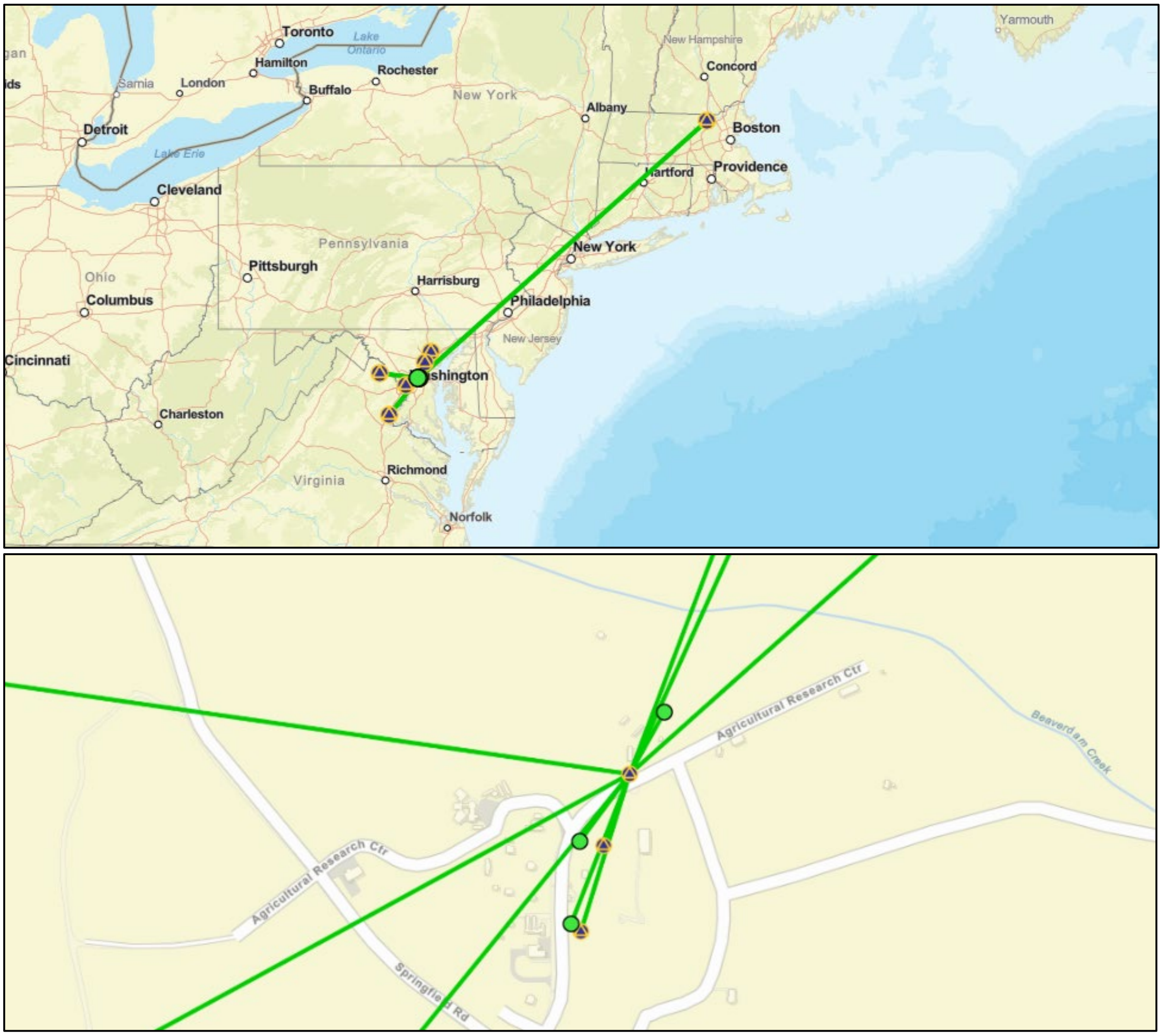
## 4.2 Leveling

No leveling was conducted for this survey.

## 4.3 GNSS

GNSS data was collected to generate 3-dimensional ITRF2020 vectors between stations at the epoch date of survey, 2024/03/30. Over multiple days, simultaneous long-session (24+ hour) observations were taken at several ground marks. Publicly available observation data was also obtained for CORS in the region.

GNSS observations were processed with a minimally constrained, “hub” design emanating from IGS tracking station GODE. Using the baseline processing engine within NGS’s OPUS Projects software, ITRF2020 vectors to the network stations and CORS were generated via ITRF2020 satellite orbits. The resulting GPS vectors were used in a combined network adjustment to align the terrestrial survey to ITRF2020.




GNSS Network Diagram

## 4.4 General comments

In the terrestrial survey, the network of ground pillars provided the availability to mount both instrument and reflectors. There were a smaller number of setups that required resection due to obstructed lines of sight. The resection principle was employed to measure between ground marks indirectly with the total station. The ground marks were occupied with the reflector targets mounted on the monument piers, marksman equipment, range poles, or fixed-height tripod. At each instrument occupation, a series of measurements were taken to the surrounding visible reflector targets. By observing common targets from different instrument occupations, the relative positions of both the instrument and targets were established.

Establishing points via circle-fitting

Coordinates of each SLR and VLBI instrument's IVP were determined using an indirect approach of circle fitting *(Jean-Claude Poyard et al, 2017, p. 27)*. The "circle-fit" theory is briefly described. A target, 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 a local coordinate system.

Total station 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 is 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 IVP.

Precise observations involving a single target/reflector secured to the VLBI, measurements from multiple instrument occupations, and numerous measurements per axis serve to ensure a millimeter level of positional precision is achieved. The SLR and VLBI IVPs were determined in this manner.

In addition to the main scheme of IVP determination, the NGS field team included an additional day to perform a similar method of IVP determination between MOBLAS-7 and SGSLR instruments. This method is documented in a 2008 survey report performed by Jim Long of Honeywell Technology Solutions, Inc. between MOBLAS-7 and the NGSSLR (now decommissioned). This method is known as Planimetry *(Jean-Claude Poyard et al, 2017, p. 26)*. The survey methods and intercomparison with the circle-fitting techniques is discussed in **Appendix A** of this report.

Coordinates for the GNSS and DORIS station geometric reference points (GRPs) were also determined using the circle-fitting routine. Three-dimensional measurements were taken to a target/reflector at multiple points around the antenna. A sufficient number of points were measured to scribe a circle in space. After accounting for reflector offsets, mechanical offsets, and mark vertical eccentricities, coordinates were computed to represent the space geodetic technique GRP. Measurements were taken from multiple locations to increase redundancy and precision.

# 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 a VLBI or SLR technique's azimuth axis, elevation axis, and axial offset. Circle-fitting was also used to determine the GNSS station GRP.

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 ***.LST*** output file.

### 5.1.2 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 **GODE** as the local origin. Complete covariance information for all network stations is available in AXIS .AXS output file.

| Surveyed topocentric coordinates, ITRF2020 (epoch 2024/03/30) | | | | | | |
|---|---|---|---|---|---|---|
| ***STATION*** | ***E(m)*** | ***N(m)*** | ***U(m)*** | ***SE(m)*** | ***SN(m)*** | ***SU(m)*** |
| ***Space geodetic technique stations*** | | | | | | |
| **GODE** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| **7622** | -40.7639 | 32.5596 | 4.0445 | 0.0003 | 0.0003 | 0.0003 |
| **7105_IVP** | -74.9504 | -124.6259 | 7.8267 | 0.0003 | 0.0003 | 0.0009 |
| **7106** | -135.7823 | -26.5874 | 4.8446 | 0.0003 | 0.0007 | 0.0017 |
| **GODN** | -22.7133 | -60.9885 | 3.3683 | 0.0003 | 0.0003 | 0.0010 |
| **GODS** | -42.5473 | -134.3771 | 4.5924 | 0.0003 | 0.0003 | 0.0010 |
| **GRFB** | -92.4681 | -184.0164 | 6.2509 | 0.0004 | 0.0003 | 0.0010 |
| **SGSLR** | -92.7315 | -112.5178 | 9.2326 | 0.0003 | 0.0003 | 0.0009 |
| ***Ground network marks*** | | | | | | |
| **7125** | -53.5428 | -161.8939 | 3.9991 | 0.0003 | 0.0003 | 0.0009 |
| **7105** | -74.9176 | -124.6169 | 4.6874 | 0.0003 | 0.0003 | 0.0009 |
| **CAL2** | -97.7291 | -187.4186 | 5.4846 | 0.0004 | 0.0003 | 0.0010 |
| **CALA** | 21.5122 | -79.5155 | 1.9200 | 0.0002 | 0.0003 | 0.0010 |
| **CALB** | 98.9750 | -141.4183 | 2.4628 | 0.0003 | 0.0003 | 0.0010 |
| **GGA1** | -78.3202 | -108.8296 | 5.6572 | 0.0003 | 0.0003 | 0.0009 |
| **GGA2** | -87.2483 | 13.0764 | -0.7966 | 0.0002 | 0.0003 | 0.0009 |
| **GGAA** | 29.4207 | 52.4357 | -0.7474 | 0.0002 | 0.0003 | 0.0010 |
| **GGAB** | -42.8312 | -57.2479 | 3.2466 | 0.0002 | 0.0003 | 0.0009 |
| **GGAC** | -21.9859 | 37.9458 | -1.8509 | 0.0002 | 0.0002 | 0.0009 |
| **GODD** | -96.2896 | -106.1242 | 3.5228 | 0.0003 | 0.0003 | 0.0009 |
| **NGS1** | -50.3570 | -128.2050 | 5.3474 | 0.0003 | 0.0003 | 0.0009 |
| **NGS2** | 26.0258 | -2.9135 | 1.2122 | 0.0002 | 0.0003 | 0.0010 |
| **NGS3** | -42.2845 | 72.1997 | -3.5758 | 0.0003 | 0.0003 | 0.0009 |
| **NORG** | -57.1525 | -85.8740 | 4.4616 | 0.0003 | 0.0003 | 0.0009 |

Topocentric Coordinates

### 5.1.3 Correlation matrix

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

### 5.1.4 Reference temperature of radio telescope

The international VLBI Service reports a reference temperature for VLBI SGT GGAO12M (7622) of 13.3 degrees Celsius. At the time of writing, file antenna-info.txt is available online.
https://raw.githubusercontent.com/anothnagel/antenna-info/master/antenna-info.txt

To account for changes in the height of the VLBI telescope due to thermal expansion/contraction, corrections were applied using the antenna components and ambient air temperatures at the time of survey operations.

| 7622 VLBI at Inst_E | | |
|---|---|---|
| Celcius T0 | 13.3 | 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 | Dimension of foundation (m). |
| h_pedestal | 6.3 | Dimension of pedestal (m). |
| **Observed Temperatures** | | |
| T_foundation | 8.0 | Six hours before optical survey observations |
| T_pedestal | 8.0 | Two hours before optical survey observations |
| **Calculations** | **Δh_total = Δh_foundation + Δh_pedestal** | |
| Δh_total | -0.00040 | |

| 7622 VLBI at Inst_E | | |
|---|---|---|
| Celcius T0 | 13.3 | 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 | Dimension of foundation (m). |
| h_pedestal | 6.3 | Dimension of pedestal (m). |
| **Observed Temperatures** | | |
| T_foundation | 6.3 | Six hours before optical survey observations |
| T_pedestal | 6.5 | Two hours before optical survey observations |
| **Calculations** | **Δh_total = Δh_foundation + Δh_pedestal** | |
| Δh_total | -0.00051 | |

| 7622 VLBI at Inst_M | | |
|---|---|---|
| Celcius T0 | 13.3 | 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 | Dimension of foundation (m). |
| h_pedestal | 6.3 | Dimension of pedestal (m). |
| **Observed Temperatures** | | |
| T_foundation | 7.9 | Six hours before optical survey observations |
| T_pedestal | 4.7 | Two hours before optical survey observations |
| **Calculations** | **Δh_total = Δh_foundation + Δh_pedestal** | |
| Δh_total | -0.00065 | |

## 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 2024/03/30)** | | | | | | |
|---|---|---|---|---|---|---|
| ***STATION*** | ***X(m)*** | ***Y(m)*** | ***Z(m)*** | ***SX(m)*** | ***SY(m)*** | ***SZ(m)*** |
| ***Space geodetic technique stations*** | | | | | | |
| **GODE** | 1130773.4549 | -4831253.5694 | 3994200.4662 | 0.0000 | 0.0000 | 0.0000 |
| **7622** | 1130729.8079 | -4831245.9582 | 3994228.3085 | 0.0003 | 0.0007 | 0.0006 |
| **7105_IVP** | 1130719.7446 | -4831352.9724 | 3994108.5712 | 0.0004 | 0.0007 | 0.0006 |
| **7106** | 1130645.9183 | -4831304.4776 | 3994182.8605 | 0.0005 | 0.0013 | 0.0012 |
| **GODN** | 1130760.6867 | -4831298.6825 | 3994155.2045 | 0.0003 | 0.0008 | 0.0007 |
| **GODS** | 1130752.1215 | -4831349.1192 | 3994098.9591 | 0.0004 | 0.0007 | 0.0007 |
| **GRFB** | 1130710.9306 | -4831392.1817 | 3994061.4382 | 0.0004 | 0.0008 | 0.0007 |
| **SGSLR** | 1130700.9430 | -4831350.6653 | 3994118.8633 | 0.0004 | 0.0007 | 0.0007 |
| ***Ground network marks*** | | | | | | |
| **7125** | 1130745.2586 | -4831368.0453 | 3994077.2075 | 0.0004 | 0.0007 | 0.0006 |
| **7105** | 1130719.2194 | -4831350.5846 | 3994106.6017 | 0.0003 | 0.0007 | 0.0006 |
| **CAL2** | 1130706.1605 | -4831394.8867 | 3994058.3118 | 0.0009 | 0.0008 | 0.0007 |
| **CALA** | 1130806.1503 | -4831298.8660 | 3994139.8990 | 0.0004 | 0.0008 | 0.0007 |
| **CALB** | 1130890.5530 | -4831319.5726 | 3994092.1482 | 0.0006 | 0.0009 | 0.0008 |
| **GGA1** | 1130713.8128 | -4831342.4153 | 3994119.4771 | 0.0006 | 0.0007 | 0.0007 |
| **GGA2** | 1130686.4852 | -4831264.8338 | 3994210.1232 | 0.0004 | 0.0008 | 0.0007 |
| **GGAA** | 1130794.4453 | -4831214.1536 | 3994240.7335 | 0.0005 | 0.0008 | 0.0007 |
| **GGAB** | 1130740.5399 | -4831300.8820 | 3994158.0334 | 0.0004 | 0.0007 | 0.0006 |
| **GGAC** | 1130746.2752 | -4831233.9172 | 3994228.7811 | 0.0004 | 0.0007 | 0.0006 |
| **GODD** | 1130695.5502 | -4831343.2373 | 3994120.2347 | 0.0006 | 0.0008 | 0.0007 |
| **NGS1** | 1130743.7654 | -4831347.6864 | 3994104.2296 | 0.0003 | 0.0007 | 0.0006 |
| **NGS2** | 1130799.4285 | -4831250.3413 | 3994198.9659 | 0.0003 | 0.0008 | 0.0007 |
| **NGS3** | 1130721.2903 | -4831216.2391 | 3994254.3073 | 0.0003 | 0.0007 | 0.0006 |
| **NORG** | 1130730.9180 | -4831322.6140 | 3994136.5591 | 0.0003 | 0.0007 | 0.0006 |

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.

7622 offset: 0.0036 m +/- 1.1 mm

For 7622, the International VLBI Service reports an axial offset of 0.0018 m.

At the time of writing, file antenna-info.txt is available online.
https://raw.githubusercontent.com/anothnagel/antenna-info/master/antenna-info.txt

Previous surveys conducted by NGS reported the following axial offsets:
7622 offset 2018: 0.0018 m

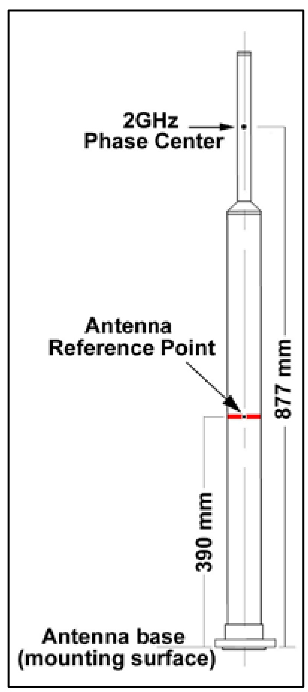
SLR axial offsets
The International Laser Ranging Service (ILRS) publishes site information for MOBLAS-7. The site log for MOBLAS-7 (GODL) used in this report was found at:
https://ilrs.cddis.eosdis.nasa.gov/network/stations/active/GODL_station_info.html?log
Differences in the table below are listed in a new-minus-old format, where Diff. = Current Survey – ILRS Offset

| SLR Mark to SLR IVP Offset | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sources | ILRS Offsets (meters) | HTSI2007 Survey (meters) | 2012 NGS Survey (meters) | Current Survey (meters) | ILRS Diff. (mm) | 2007 Diff. (mm) | 2012 Diff. (mm) |
| CDP STATION 7105 to MOBLAS-7 IVP (dN) | -0.009 | -0.007 | -0.0087 | -0.0090 | 0.0 | -2.0 | -0.3 |
| (dE) | -0.032 | -0.034 | -0.0327 | -0.0328 | -0.8 | +1.2 | -0.1 |
| (dU) | 3.138 | 3.138 | 3.1379 | 3.1393 | +1.3 | +1.3 | +1.4 |

Offset comparisons at MOBLAS-7

Geometric properties of DORIS station
Multiple points were surveyed to determine the geometric properties of the DORIS station.

| SURVEYED TIES FROM GRFB MARK | | | |
|---|---|---|---|
| ***STATION*** | ***DE (m)*** | ***DN (m)*** | ***DU (m)*** |
| **GRFB MARK** | 0.0000 | 0.0000 | 0.0000 |
| **GRFB BASE** | -0.0029 | 0.0010 | 0.4168 |
| **GRFB ARP** | -0.0022 | 0.0009 | 0.8068 |
| **GRFB PHASE CTR** | -0.0025 | 0.0012 | 1.2938 |



Geoid model used

Astronomical observations were conducted at GGAB to measure the deflection of the vertical. Considering the limited size of the observatory site (less than 300 meters by 300 meters), the measured values are assumed to be applicable at each of the remaining stations. From the measured deflections, geoid height differences were determined via the astronomical leveling technique. These differences were then applied to an absolute geoid height at GGAB from NGS's xGEOID20B model. From this, geoid heights at all stations were obtained. Examination of the measured deflections and geoid heights reveals a tilt in the geoid surface from Northwest to Southwest.

## 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 **NGSWASH2403GA.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       =     39

             Number of Observations   =   2140
             Number of Unknowns       =    198
             Number of Redundant Obs  =   1942

 Observation   Count   Sum Squares         Error
                         of StdRes         Factor
 Coordinates       3       0.000           0.000
  Directions     641     600.030           1.016
   Distances     576     536.184           1.013
 Az/Bearings       8       7.649           1.026
     Zeniths     629     567.450           0.997
  Elev Diffs       1       0.000           0.000
  GPS Deltas     282     275.774           1.038

       Total    2140    1987.087           1.012

       The Chi-Square Test at 5.00% Level Passed
            Lower/Upper Bounds (0.969/1.031)
```

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 2024/03/30) | | | |
|---|---|---|---|
| ***STATION*** | ***X (m)*** | ***Y (m)*** | ***Z (m)*** |
| **GODE** | 1130773.4550 | -4831253.5695 | 3994200.4662 |
| **7622** | 1130729.8142 | -4831245.9495 | 3994228.2958 |
| **7125** | 1130745.2634 | -4831368.0244 | 3994077.2086 |
| **7105** | 1130719.2240 | -4831350.5737 | 3994106.6062 |
| **GODN** | 1130760.6855 | -4831298.6754 | 3994155.2020 |
| **GODS** | 1130752.1171 | -4831349.0993 | 3994098.9634 |
| **GRFB** | 1130710.9353 | -4831392.1671 | 3994061.4306 |

IERS computed coordinates

| Surveyed tie vs. IERS computed tie | | | |
|---|---|---|---|
| NGS 2024 geocentric tie discrepancies | | | |
| ***STATION*** | ***X (mm)*** | ***Y (mm)*** | ***Z (mm)*** |
| **GODE** | -0.1 | 0.1 | 0.0 |
| **7622** | -6.3 | -8.7 | 12.7 |
| **7125** | -4.8 | -20.9 | -1.1 |

| | | | |
|---|---|---|---|
| **7105** | -4.6 | -10.9 | -4.5 |
| **GODN** | 1.2 | -7.1 | 2.5 |
| **GODS** | 4.4 | -19.9 | -4.3 |
| **GRFB** | -4.7 | -14.6 | 7.6 |

Table 7: Tie discrepancies between surveyed and computed ties (surveyed minus computed)

Comparing against the ITRF2020 computed coordinates, the current survey has a maximum tie discrepancy of 20.9 millimeters in the Y component for the CDP STATION 7125 ground monument.

Comparing ITRF2020 computed coordinates of SGTs, the current survey has a maximum tie discrepancy of 19.9 millimeters in the Y component for GODS.

### 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 2012 previous survey in ITRF2008 (epoch 2012/07/14). 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 2012)** | | | |
|---|---|---|---|
| **Topocentric tie discrepancies** | | | |
| ***STATION*** | ***DE (mm)*** | ***DN (mm)*** | ***DU (mm)*** |
| GODE | 0.0 | 0.0 | 0.0 |
| 7622 | 0.6 | 1.1 | 0.6 |
| 7125 | -1.0 | 1.5 | 0.6 |
| 7105 | -0.8 | 1.6 | 0.6 |
| GODN | -0.1 | 1.4 | 0.5 |
| GODS | -0.8 | 1.8 | 0.3 |
| GRFB | -1.2 | 1.7 | 0.6 |
| CAL2 | -1.2 | 1.7 | 0.6 |
| CALB | -0.9 | 0.3 | 0.5 |
| GGA2 | 0.2 | 1.7 | 0.5 |
| GGAA | 0.8 | 0.6 | 0.2 |
| NORG | -0.4 | 1.5 | 0.7 |

Table 8: Tie discrepancies between current survey and previous survey (current minus previous)

## 6 Planning aspects

Physical address of project site:
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Recommendations

Reconnaissance prior to scheduled surveys should be performed in the fall prior to scheduling survey work to ascertain condition of survey piers and lines of sight. Clearing of vegetation may be necessary and on-site managers should be given a comprehensive reconnaissance report to coordinate with groundskeeping. Surveys are best conducted in early-mid Spring before grasses and other vegetation growth.

Coordinate the observing schedule with the on-site technicians in advance to take advantage of maintenance down time. During survey observations, site personnel will drive the radio telescopes under survey team direction. A climbing harness is required to utilize the cherry picker boom lift.

Radomes for GODN and GODS include the standard safety fasteners, but also rivets. Coordinate with JPL to request permission for radome removal.

When working around the DORIS antenna, it should be turned off. Coordinate the observing schedule with IGN.

Calibration piers A and C are showing signs of deterioration.

Working with Jan Mcgarry has been a pleasure. Our team appreciates the careful planning and coordination she has provided to make this a successful survey. We wish her well in her phased retirement!

## 7 References

### 7.1 Name of person(s) responsible for observations

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15351 Office Drive
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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

Breidenbach, Steven et al (2012). LOCAL TIE INFORMATION REPORT IERS NETWORK SITE: WASHINGTON (DC).
https://www.ngs.noaa.gov/corbin/iss/reports/WashingtonSiteLocalTieSurvey.pdf

Long, Jim, Honeywell Technology Solutions, Inc. (2008). Survey Report for MOBLAS 7 – NGSLR Intercomparison *(Memorandum)*

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 DORIS Service. https://ids-doris.org/

International VLBI Service for Geodesy & Astronomy. https://ivscc.gsfc.nasa.gov/

Geodetic Astronomy - Ryan A. Hardy, PhD.
https://geodesy.noaa.gov/web/science_edu/presentations_library/files/geodetic_astronomy_at_ngs.pdf

# Appendix A

In 2008, a field survey reported by Jim Long of Honeywell Technology Solutions, Inc. provided an intercomparison of MOBLAS 7 – NGSLR (decommissioned). This survey performed a survey technique known as planimetry. As common practice, NGS performs circle-fitting as the method to determine the invariant point (IVP). The result of the two methods is essentially the same and that is to provide a highly precise vector in-between all Space Geodetic Techniques. At the request of NASA and KBR, the NGS field survey team replicated this measurement technique to produce a vector in-between MOBLAS-7 and SGSLR with the goal of achieving 1 millimeter (mm) accuracy.

## Instrumentation

## Tacheometers, EDMI, theodolites

### Description

Leica AT402, S/N 392045 (Laser Tracker)
Specifications:
Angular measurement uncertainty of instrument: +/- 0.5"
Combined uncertainty of distance measurement throughout instrument range: +/- 0.014 mm

### Calibrations

Leica AT402, S/N 392045
Certified by Hexagon Metrology, North Kingstown, RI on 2023/06/23.

## 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
- 50 mm vertical offset

**Specialized Equipment**

Micro-Controle 2-Dimensional Translation Stage
Trivet
NGS-Supplied Multi-Technique Adapter (MTA)

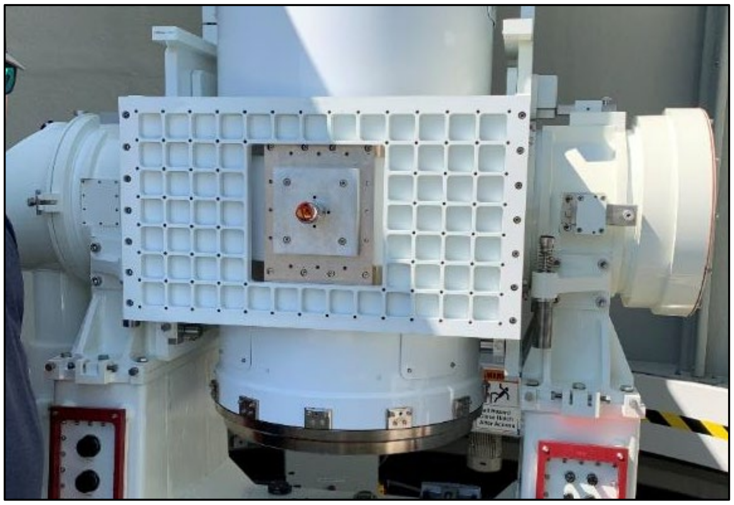
Prior to observations, the telescope for MOBLAS-7 was rotated 180° from the operational orientation. This required the NASA authorized team to remove various electrical cabling and limiters to free the scope for this rotation. Once the rotation was complete, the underside of the SLR is equipped with a trivet plate. While this trivet plate allows for the mounting of the trivet carrier, the plate itself is not completely centered on the azimuth axis. For MOBLAS-7, the azimuth axis of rotation was determined by placing the 2-dimensional translation stage and survey target on top of the trivet plate that is attached to the underside of the SLR.

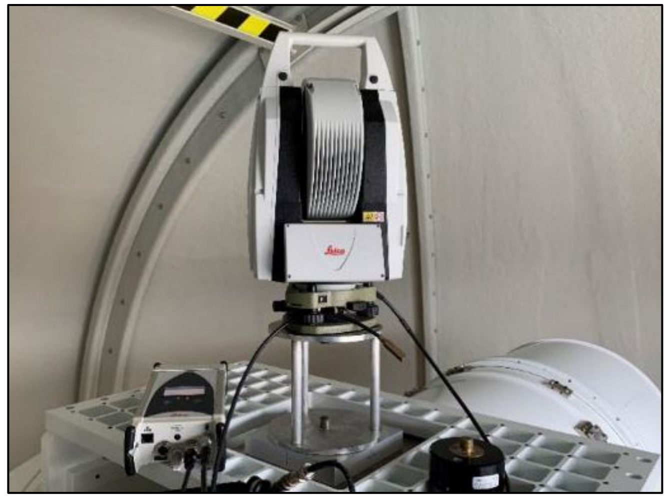

2-dimensional translation stage mounted on MOBLAS-7

The AT402 Laser Tracker occupied the NGS1 Pier located approximately 25 meters East of MOBLAS-7. Using the Spatial Analyzer collection software, AT402 Laser Tracker measurements were made to the reflector, then the SLR was rotated 90° in azimuth. The 1.5" BRR reflector was repointed so that an additional measurement could be performed. An inverse was computed between the two measurements and the translation stage was used to adjust the reflector about 1/2 the distance. This process was iterated multiple times until both measurements 90° opposed were ~1 mm horizontal. Additional ties were measured to CDP STATION 7125, CAL2 and GGAB. Due to time constraints and the possibility of precipitation, the team did not perform all 4 quadrant measurements.

The MOBLAS-7 SLR does not have a reference point for the elevation axis. After discussion with site managers, the circle-fitting method used on previous days of this survey from 3 independent setups and 6 elevation axis circles would be used to determine the vertical reference point of the SLR. The target height relative to the vertical point of reference is 0.7749 meters.

The SGSLR is equipped with two reference points. Plunging the scope 180° reveals a 5/8" x 11 threaded mount point. A threaded stud is required to attach these components and is considered the azimuth reference point (aka the center of rotation for azimuth). The 2nd reference point is a divot on the vertical face of the instrument that is presumed to be the vertical reference point (aka center of rotation for elevation axis).


Azimuth Reference Point


Azimuth Reference Point (measuring position) with MTA


Elevation Reference Point

With the AT402 Laser Tracker still occupying the NGS1 pier, measurements were taken to both reference points. The NGS-developed Multi Technique Adapter (MTA) allowed a retroreflector to be mounted on the lower plate of the adapter (MTA shown in upper-right photo). Instrument operators ensured the SGSLR was level during these measurements. A shorter 5/8" x 11 stud would be necessary to mount the tribrach to the SGSLR plate directly.

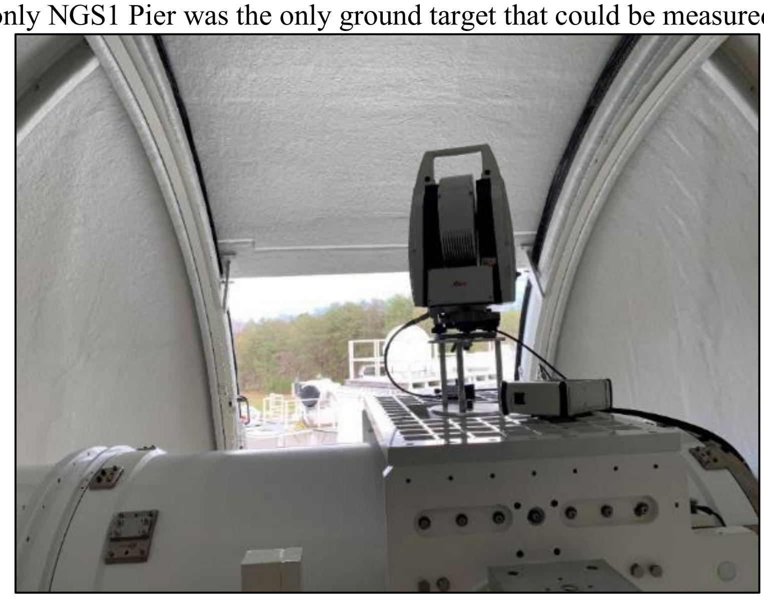
**MOBLAS-7 Occupation**

The AT402 Laser Tracker was setup to occupy the setup on MOBLAS-7 to observe the Azimuth and Elevation reference points on the SGSLR. Ground targets included in this setup were GGAB and NGS1.


AT402 Laser Tracker mounted on MOBLAS-7

**SGSLR Occupation**

The final instrument setup occupied the mounting plate on the SGSLR and a retroreflector was placed back on the mounting plate and equipment assembly on MOBLAS-7. Due to the small opening in the SGSLR enclosure, only NGS1 Pier was the only ground target that could be measured.



Instrument Occupation of SGSLR with MOBLAS-7 in background

## Results

Terrestrial observations and analysis were conducted with commercially available software Spatial Analyzer (version 2022.3.1123.3) from New River Kinematics. Least squares adjustments were conducted with commercially available software Star*Net (version 12.0.3.5251) from MicroSurvey. Coordinate transformations and SINEX generation were conducted with AXIS software from Geoscience Australia.

The measurements described in this appendix were incorporated with the terrestrial and GNSS measurements observed as part of the main survey scheme. ITRF2020 (EDS) coordinates were computed for these sets of measurements.

| geocentric adjusted coordinates, ITRF2020 (epoch 2024/03/30) | | | |
|---|---|---|---|
| **STATION** | **X(m)** | **Y(m)** | **Z(m)** |
| MOB7_IVP | 1130719.7473 | -4831352.9711 | 3994108.5710 |
| SGSLR_IVP | 1130700.9445 | -4831350.6645 | 3994118.8619 |

**Topocentric coordinate comparison**

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 **MOB7_IVP** as the local origin for the measurements discussed in this appendix (*Planimetric Technique)*. Respectively, the topocentric coordinate estimates with station **7105_IVP** as the local origin for the measurements from the full network survey (*Circle-Fit Technique)*.

| Surveyed topocentric coordinates, ITRF2020 (epoch 2024/03/30) | | | | |
|---|---|---|---|---|
| **STATION** | **E(m)** | **N(m)** | **U(m)** | **3D(m)** |
| **Planimetric Technique** | | | | |
| MOB7_IVP | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| SGSLR_IVP | -17.7829 | 12.1064 | 1.4052 | 21.5585 |
| 7105 | 0.0304 | 0.0105 | -3.1395 | 3.1397 |
| **Circle-Fit Technique** | | | | |
| 7105_IVP | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| SGSLR_IVP | -17.7812 | 12.1081 | 1.4060 | 21.5582 |
| 7105 | 0.0328 | 0.0091 | -3.1394 | 3.1396 |
| **Planimetric vs. Circle-Fit** | | | | |
| **STATION** | **E(mm)** | **N(mm)** | **U(mm)** | **3D(mm)** |
| MOB7/7105_IVP | 0.0 | 0.0 | 0.0 | 0.0 |
| SGSLR_IVP | -1.7 | -1.7 | -0.8 | 2.5 |
| 7105 | -2.4 | 1.4 | -0.1 | 2.8 |

Topocentric Coordinate Comparison showing Planimetry Technique vs. Circle-fit