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

LOCAL TIE INFORMATION REPORT
U.S. NAVAL RESEARCH LABORATORY (NRL) OPTICAL TEST FACILITY

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Revised Report: June 2021

Introduction

In June 2019, the National Geodetic Survey (NGS) conducted a special purpose survey at the U.S. Naval Research Laboratory's (NRL) Optical Test Facility (OTF), located at the Midway Research Center in Stafford, Virginia. The primary purpose of the survey was to establish geometric ties between a laser ranging telescope, old and new ground calibration targets, and GNSS station MRC1. The geometric vectors were aligned to the latest realization of the International Terrestrial Reference Frame (ITRF2014) at the epoch date of the survey (2019/06/28).

A secondary purpose of the survey was to establish a high precision geodetic network of geodetic technique instrumentation and ground control points nearby the NGS's Testing & Training Center facility located in Woodford, VA well suited for the development and refinement of local site survey field procedures and instrumentation.

The NRL OTF consists of a one-meter high-precision laser telescope and gimbal system co-located with a new high-accuracy continuously operating GNSS station. The OTF is an Associate Member station of the International Laser Ranging Service (ILRS). NRL routinely conducts satellite laser ranging (SLR) campaigns, diagnosing timing systems, updating atmospheric drag models, and evaluating global navigation satellite system (GNSS) ephemerides. The GNSS station (MRC1) was added in 2017 and is part of the International GNSS Service Network.

1 Site description

IERS site name:	Stafford
IERS site number:	49654
Country name:	United States of America
Dates of survey:	June 25-29, 2019
Longitude:	W 77° 22'
Latitude:	N 38° 29'
Tectonic plate:	NOAM

Geodetic Technique	Name	DOMES#	ITRF Description
SLR	7865 MARK	49654M001	Brass marker with divot
SLR	7865 IVP	n/a	Intersection of telescope axes (Invariant Point)
GNSS	MRC1	49654M002	SCIGN mount mark

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

2 Instrumentation

2.1 Tacheometers, EDMI, theodolites

2.1.1 Description

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

2.1.2 Calibrations

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

2.1.3 Auxiliary equipment

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

2.1.4 Analysis software

Terrestrial observations and analysis were conducted with commercially available software Spatial Analyzer (version 2017.08.11_29326) from New River Kinematics. Least squares adjustments were conducted with commercially available software Star*Net (version 9,1,4,7868) from MicroSurvey. Coordinate transformations and SINEX generation were conducted with AXIS software from Geoscience Australia.

2.2 GNSS units

2.2.1 Receivers

Trimble NetR5, P/N: 62800-00, S/Ns: 4624K01583, 4624K01648, 4624K01648, 4624K01590
Specifications for Static GPS Surveying:
  Horizontal: +/- 5 mm + 0.5 ppm RMS
  Vertical: +/- 5 mm + 1 ppm RMS

2.2.2 Antennas

Trimble GPS ground plane antenna, Zephyr Geodetic Model 2, P/N 41249-00, S/Ns: 12481390, 60165452 , 12344336, 12545667.

2.2.3 Analysis software

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

2.3 Leveling

No leveling instrumentation was used in this survey.

2.3.1 Leveling instruments

Not applicable.

2.3.2 Leveling rods

Not applicable.

2.3.3 Checks carried out before measurements

Not applicable.

2.4 Tripods

Wooden surveying tripods, with collapsible legs were, used to support surveying instrumentation. Fixed-height range poles with attached tripod support legs were used with target reflectors. A Seco collapsible-height tripod was with a target reflector for a temporary mark established on the roof of the operations building.

Fixed-height range poles for reflectors and GNSS antennas

2.5 Forced-centering devices

Multiple forced centering devices were used to center the instrumentation over the site's marks. For stations PIER NORTH, PIER EAST, and PIER SOUTH, a "multipurpose tripod adapter" (MTA) was used to mount reflectors and GPS antennas simultaneously.

Forced-centering device to occupy a mark

MTA, Reflector and GNSS occupying PIER NORTH

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 setup

3.1 Ground network

The site has a network of existing ground marks which were recovered and incorporated into this survey. Non-monumented temporary points were also established to facilitate the survey. The SLR telescope has an inaccessible Invariant Point (IVP) and an accessible Geometric Reference Point (GRP), located at the base of and adjacent to the instrument. The GRP for GNSS station MRC1 is inaccessible.

A previous survey of the site was conducted in 2016 by the National Geodetic Survey. 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 with exception of the new GRP for MRC1 (established July, 2017).

3.1.1 Listing

Current Survey	DOMES	IERS 4-char code	Previous Survey Point Name	NGS PID
Space geodetic technique stations				
7865 MARK	49654M001	7865	SLRM	--
7865 IVP	n/a	7865	SLR1	--
MRC1	49654M002	MRC1	--	--
Ground network marks				
3 01-3	--	--	3 1-03	--
33	--	--	33	--
34	--	--	34	--
PIER EAST	--	--	PIER EAST	--
PIER NORTH	--	--	PIER NORTH	--
PIER SOUTH	--	--	PIER SOUTH	--

Table 2: Listing of SGT stations and ground network marks

Ground network mark descriptions

PIER SOUTH The monument is a PVC-encased concrete pier, approximately 60 cm in diameter and projecting 2 meters above the surrounding ground surface. The monument base is reported by MRC personnel to be substantial. The associated mark is flush with the top surface of and near the center of a 5/8-11 inch threaded hole drilled into the center of a 10-cm diameter stainless steel billet. Consult with MRC personnel for details.

PIER SOUTH

PIER EAST The monument is a PVC-encased concrete pier, approximately 60 cm in diameter and projecting 1.5 meters above the surrounding ground surface. The monument base is reported by MRC personnel to be substantial. The associated mark is flush with the top surface of and near the center of a 5/8-11 inch threaded hole drilled into the center of a 10-cm diameter stainless steel billet. Consult with MRC personnel for details.

PIER EAST

PIER NORTH The monument is a PVC-encased concrete pier, approximately 60 cm in diameter and projecting 1.7 meters above the surrounding ground surface. The monument base is reported by MRC personnel to be substantial. The associated mark is flush with the top surface of and near the center of a 5/8-11 inch threaded hole drilled into the center of a 10-cm diameter stainless steel billet. Consult with MRC personnel for details.

PIER NORTH

33 The mark is the center of the bottom of a dimple cast into the top center of a MRC disk stamped 33 and set into the top of a poured-in-place concrete post 20 cm in diameter and flush with the ground. Consult MRC personnel for details.

33

3 01-3 The mark is the center of the bottom of a dimple cast into the top center of a brass disk stamped 1999 3 01-3 and set into the top center of a poured-in-place concrete post 20 cm in diameter and flush with the ground. Consult with MRC personnel for details.

3 1-03

34 The mark is the center of the bottom of a dimple cast into the top center of a brass disk stamped 34 and set into the top center of a poured-in-place concrete post 20 cm in diameter and flush with the ground. Consult with MRC personnel for details.

34

7865_MARK The mark is the center of the bottom of a dimple cast into the top center of a brass disk cemented into a drill hole in the concrete floor of the SLR building. This section of the floor is also the massive foundation for the SLR. Consult with MRC personnel for details.

7865 MARK

SLR Calibration Check Points

RADAR TOWER The mark is the center of the front surface (nearest the SLR) of a 25.4 mm in diameter, uncoated, fused silica corner cube (retro-reflector) mounted onto the framework of the steel tower support a radar dome. Consult with MRC personnel for details. This mark was collected with a single observation from the laser tracker instrument. The retro reflector for this station appeared to be in poor condition and, therefore, would not provide a return signal to the instrument on the day of collection.

WATER TOWER The mark is the center of the front surface (nearest the SLR) of a 25.4 mm in diameter, uncoated fused silica corner cube (retro-reflector) mounted onto the steel railing of an elevated water tank. Consult with MRC personnel for details. This mark was obstructed by trees as an SLR check point, therefore, was not observed on the day of survey.

3.1.2 Map of network

3.2 Representation of technique reference points

3.2.1 VLBI

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

3.2.2 SLR

7865 The invariant point (IVP) is a theoretical point. For the NRL Optical Test Facility SLR instrument, the IVP can be defined as the intersection of the azimuth axis with the common perpendicular of the azimuth and elevation axis.

The SLR geometric reference point (GRP) is a dimple cast into the top center of a brass disk cemented into a drill hole in the concrete floor of the SLR building. The mark was directly occupied this survey. The SLR IVP is eccentric from the mark by -1.1984 m North, -0.0083 m East, and 4.0555 m Up. To distinguish between the SLR IVP and the GRP, the two points are herein identified as 7865 IVP and 7865 MARK.

SLR telescope foundation with 7865 MARK occupied

3.2.3 GNSS
The site hosts one active GNSS technique station (MRC1). The station is recognized by the International GNSS Service (IGS). An indirect approach as discussed later in Section 4.4, was used to determine position of the Geometric Reference Point (GRP) in the survey, as the antenna was not removed.

MRC1 The GRP is represented by a divot in a SCIGN antenna mount, affixed to the top of a deep drill braced monument. MRC1 is occupied by a choke ring antenna, Septentrio SEPCHOKE_B3E6 with SPKE radome. Per the site log, the ARP is eccentric from the GRP by 0.0 m East, 0.0 m North, and 0.0083 m Up.

MRC1

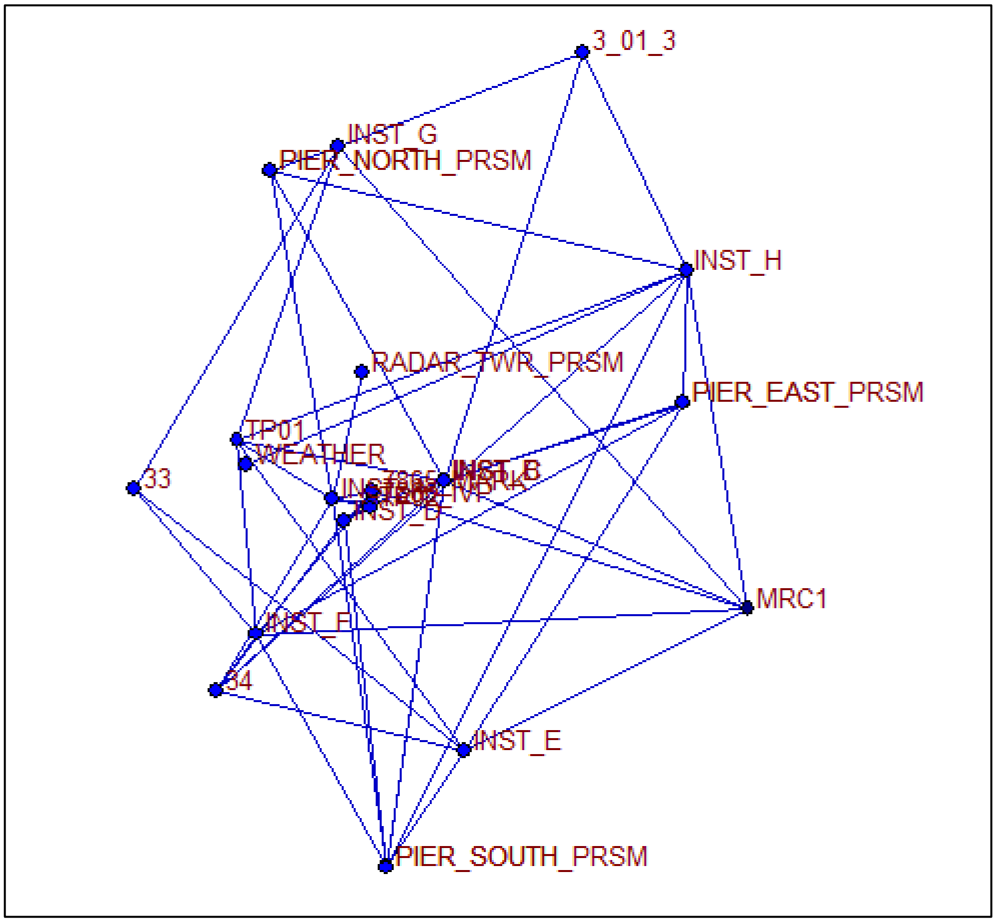
3.2.4 DORIS
This space geodetic technique was not represented at the site at the time of survey.

4 Observations

4.1 Terrestrial survey
The terrestrial survey was completed using an absolute laser tracker system. The instrument measured horizontal angles, vertical angles, and distances to retro-reflector targets used to position the marks and techniques. GNSS observations were also collected to support the terrestrial survey.

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. Table 3 lists all vertical offsets used to correct target heights to associated ground marks and GRPs.

Spatial Analyzer software was used for recording observations and to perform field-level data quality checks for all laser tracker and 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.



Network Stations at NRL Optical Test Facility

Vertical offsets of terrestrial survey stations (units in meters, reported eccentricities are from site logs)

STATION	OFFSET 1	OFFSET 2	PRISM	NRL Cal Pier Adapter	TOTAL OFFSET
7865 IVP	Circle-fit 0.0000				0.0000
7865 MARK	Range Pole A 1.0426		Brunson Nest with Prism 0.0526		1.0952
PIER SOUTH		MTA B, Bottom Plate 0.0098	Leica Nest with Prism 0.0550	0.0069	0.0717
PIER NORTH		MTA A, Bottom Plate 0.0098	Leica Nest with Prism 0.0550	0.0068	0.0716
PIER EAST		MTA C, Bottom Plate 0.0098	Leica Nest with Prism 0.0550	0.0073	0.0721
MRC1	Reported Marker-ARP Ecc. 0.0083	Width of Leica Base 0.0099	Leica Nest with Prism (inverted) -0.0550		-0.0368

34	Range Pole D		Brunson Nest with Prism		
	1.0426		0.0526		1.0952
33	Range Pole B		Brunson Nest with Prism		
	1.0422		0.0526		1.0950
3 01-3	Range Pole E		Brunson Nest with Prism		
	1.0424		0.0526		1.0952

Table 3

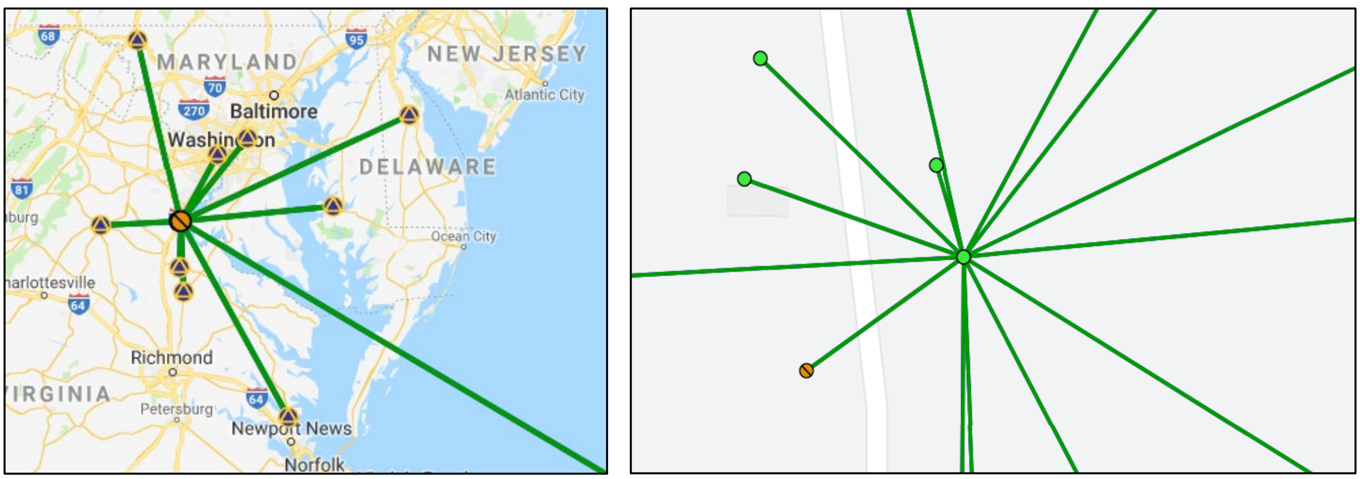
4.2 Leveling

No leveling was conducted for this survey.

4.3 GNSS

GNSS data was collected to generate 3-dimensional ITRF2014 vectors between stations at the epoch date of survey, 2019/06/28. Over multiple days, simultaneous long-session (20+ 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 MRC1. Using the baseline processing engine within NGS's Beta OPUS Projects software, ITRF2014 vectors to the network stations and CORS were generated via ITRF2014 satellite orbits. The resulting GPS vectors were used in a combined network adjustment to align the terrestrial survey to ITRF2014.



GNSS network diagrams

<u>Vertical offsets of GNSS survey stations</u>
(units in meters, reported eccentricities are from station site logs)

Station	MTA	NRL Cal Pier Adapter	ARP ht (m)
PIER SOUTH	B		
	0.1507	0.0069	0.1576
PIER NORTH	A		
	0.1506	0.0068	0.1574
PIER EAST	C		
	0.1507	0.0073	0.1580
TP01	D		
	0.1507		0.1507

Table 4

4.4 General comments

Resection method for terrestrial observations

In the terrestrial survey, the resection principle was employed to measure between ground marks indirectly with the laser tracker. The ground marks were occupied with the reflector targets mounted on range poles. The instrument did not occupy the marks directly but was instead setup at arbitrary points between the marks. 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.

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

Establishing points via circle-fitting

Coordinates of the SLR instrument IVP were determined using an indirect approach of circle fitting. The "circle-fit" theory is briefly described. A point, as it revolves about an axis, scribes an arc. The arc defines a circle and a plane simultaneously. The axis can then be defined as it passes through the center of the circle, orthogonal to the plane. By assigning coordinates to the points observed along an arc rotated about an axis, one can assign parameters to the axis relative to a local coordinate system.

Laser tracker measurements project coordinates from the local ground network to a target/reflector attached to a geodetic technique instrument as it moves about the instrument's axis, thereby providing the necessary information to locate a single axis. The same procedure 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 SLR telescope, measurements from three instrument occupations, and numerous measurements per axis serve to ensure a millimeter level of positional precision is achieved. The SLR IVP was determined in this manner.

Coordinates for the GNSS station GRP 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 the 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 ITRF2014 (epoch date of survey) using the GNSS observations in a combined geodetic adjustment. AXIS software was used to compile topocentric coordinate estimates with station 7865 MARK as the local origin. Station 7865 MARK is the site marker. Complete covariance information for all network stations is available in AXIS ***.AXS*** output file.

Surveyed topocentric coordinates, ITRF2014 (epoch 2019/06/28)						
STATION	***E(m)***	***N(m)***	***U(m)***	***SE(m)***	***SN(m)***	***SU(m)***
Space geodetic technique stations						
7865 MARK	0.0000	0.0000	0.0000	0.0001	0.0004	0.0001
7865 IVP	-0.0083	-1.1984	4.0554	0.0001	0.0004	0.0001
MRC1	40.0744	-12.9246	3.3281	0.0000	0.0000	0.0000
Ground network marks						
33	-25.3648	0.5560	-0.7186	0.0002	0.0006	0.0001
34	-16.8649	-20.8622	-1.0522	0.0001	0.0005	0.0001
3 01 3	23.1044	46.1471	0.8451	0.0006	0.0002	0.0001
PIER EAST	33.3959	8.8146	3.2089	0.0002	0.0001	0.0001
PIER NORTH	-10.4620	33.8909	2.1071	0.0004	0.0005	0.0001
PIER SOUTH	0.9919	-39.8076	1.5708	0.0003	0.0004	0.0001

Table 5

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

Not applicable.

5.2 GNSS

5.2.1 Analysis software

NGS's Beta OPUS Projects software was used to process and analyze ITRF2014 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 ITRF2014 (epoch data of survey). Complete covariance information for all network station is available in AXIS ***.AXS*** output file.

Surveyed geocentric coordinates, ITRF2014 (epoch 2019/06/28)						
STATION	***X(m)***	***Y(m)***	***Z(m)***	***SX(m)***	***SY(m)***	***SZ(m)***
Space geodetic technique stations						
7865 MARK	1092770.3621	-4877220.3490	3948976.1635	0.0001	0.0003	0.0003
7865 IVP	1092771.2110	-4877224.1758	3948977.7501	0.0001	0.0003	0.0003
MRC1	1092811.7955	-4877221.9799	3948968.1202	0.0000	0.0000	0.0000
Ground network marks						
33	1092745.4123	-4877225.0081	3948976.1513	0.0001	0.0004	0.0005
34	1092756.5645	-4877235.9053	3948959.1814	0.0002	0.0003	0.0004
3_01_3	1092786.7715	-4877187.9112	3949012.8051	0.0005	0.0002	0.0002
PIER_EAST	1092802.2994	-4877210.1437	3948985.0595	0.0002	0.0001	0.0001
PIER_NORTH	1092755.9012	-4877203.6587	3949003.9887	0.0004	0.0004	0.0004
PIER_SOUTH	1092777.0179	-4877245.5123	3948945.9872	0.0003	0.0002	0.0003

Table 6: Coordinate estimates for network stations

Local tie vectors emanating from the site marker, station 7865 MARK, are provided below for the ITRF space geodetic techniques using the coordinates determined this survey.

Surveyed topocentric ties				
STATION	***E(m)***	***N(m)***	***U(m)***	**DIST (m)**
7865 MARK	0.0000	0.0000	0.0000	0.0000
7865 IVP	-0.0083	-1.1984	4.0554	4.2288
MRC1	40.0744	-12.9246	3.3281	42.2384
Surveyed geocentric ties				
STATION	***X(m)***	***Y(m)***	***Z(m)***	**DIST (m)**
7865 MARK	0.0000	0.0000	0.0000	0.0000
7865 IVP	0.8489	-3.8268	1.5866	4.2288
MRC1	41.4334	-1.6309	-8.0433	42.2384

Table 7: Local tie vectors emanating from 7865 MARK

5.3 Additional parameters

For the benefit of the site operators, topocentric and geocentric coordinates are provided relative to the invariant point of the SLR telescope. Additional stations are included representing the positions of the reflectors used for calibration of the SLR system. For stations designated with "PRISM," corrections for prism constant and target height have not been applied. The reported position is of the optical vertex of the prism found in situ, as measured by the NGS laser tracker.

Surveyed topocentric coordinates, ITRF2014 (epoch 2019/06/28)						
STATION	***E(m)***	***N(m)***	***U(m)***	***SE(m)***	***SN(m)***	***SU(m)***
Space geodetic technique stations						
7865 IVP	0.0000	0.0000	0.0000	0.0001	0.0004	0.0001
7865 MARK	0.0083	1.1984	-4.0554	0.0001	0.0004	0.0001
MRC1	40.0827	-11.7262	-0.7273	0.0000	0.0000	0.0000
Ground network marks						
33	-25.3565	1.7544	-4.7740	0.0002	0.0006	0.0001

34	-16.8566	-19.6638	-5.1076	0.0001	0.0005	0.0001
3 01-3	23.1128	47.3455	-3.2103	0.0006	0.0002	0.0001
PIER EAST	33.4042	10.0130	-0.8465	0.0002	0.0001	0.0001
PIER E PRISM	33.4324	10.0225	-0.7484	0.0003	0.0003	0.0002
PIER NORTH	-10.4536	35.0893	-1.9483	0.0004	0.0005	0.0001
PIER N PRISM	-10.4661	35.1180	-1.8487	0.0005	0.0005	0.0002
PIER SOUTH	1.0015	-38.6092	-2.4846	0.0003	0.0004	0.0001
PIER S PRISM	1.0002	-38.6396	-2.3825	0.0004	0.0004	0.0002
WEATHER	-13.3321	4.1680	-0.2808	0.0003	0.0007	0.0004

Table 8

Surveyed geocentric coordinates, ITRF2014 (epoch 2019/06/28)						
STATION	***X(m)***	***Y(m)***	***Z(m)***	***SX(m)***	***SY(m)***	***SZ(m)***
Space geodetic technique stations						
7865 IVP	1092771.2110	-4877224.1758	3948977.7501	0.0001	0.0003	0.0003
7865 MARK	1092770.3621	-4877220.3490	3948976.1635	0.0001	0.0003	0.0003
MRC1	1092811.7955	-4877221.9799	3948968.1202	0.0000	0.0000	0.0000
Ground network marks						
33	1092745.4123	-4877225.0081	3948976.1513	0.0001	0.0004	0.0005
34	1092756.5645	-4877235.9053	3948959.1814	0.0002	0.0003	0.0004
3 01-3	1092786.7715	-4877187.9112	3949012.8051	0.0005	0.0002	0.0002
PIER EAST	1092802.2994	-4877210.1437	3948985.0595	0.0002	0.0001	0.0001
PIER E PRISM	1092802.3424	-4877210.2066	3948985.1280	0.0002	0.0002	0.0002
PIER NORTH	1092755.9012	-4877203.6587	3949003.9987	0.0004	0.0004	0.0004
PIER N PRISM	1092755.9022	-4877203.7200	3949004.0832	0.0004	0.0004	0.0004
PIER SOUTH	1092777.0179	-4877245.5123	3948945.9872	0.0003	0.0002	0.0003
PIER S PRISM	1092777.0382	-4877245.6090	3948946.0270	0.0005	0.0003	0.0003
WEATHER	1092757.5861	-4877224.3444	3948980.8372	0.0003	0.0005	0.0006

Table 9

SLR telescope axial offsets

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

7865 offset: 0.1 mm +/- 0.1 mm

Geoid model used

No geoid model was used.

5.4 Transformations

ITRF2014 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 ITRF2014 at the epoch date of survey.

5.5 Description of SINEX generation

AXIS software was used to generate a SINEX file with full variance-covariance matrix information. All stations with DOMES numbers are included in SINEX file ***NGSMRC11906GA.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      =     33

                Number of Observations  =    660
                Number of Unknowns      =    126
                Number of Redundant Obs =    534

        Observation   Count   Sum Squares         Error
                                of StdRes         Factor
        Coordinates       3         0.000          0.000
         Directions     163       130.604          0.995
          Distances     165       130.864          0.990
            Zeniths     167       137.413          1.008
         GPS Deltas     162       169.446          1.137

              Total     660       568.328          1.032

              The Chi-Square Test at 5.00% Level Passed
                   Lower/Upper Bounds (0.940/1.060)
```

<u>Comparison with IERS computed tie</u>

ITRF coordinates not available for any stations onsite. No comparison possible.

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 previous survey in ITRF2008 (epoch 2005.00). Topocentric tie vector comparisons are provided for the common surveyed stations. Complete coordinate information is available in the included data products.

Surveyed ties vs. Previous survey (National Geodetic Survey 2016) Topocentric tie discrepancies			
STATION	***DE (mm)***	***DN (mm)***	***DU (mm)***
PIER_NORTH	*0.0*	*0.0*	*0.0*
33	*-3.4*	*-4.0*	*-1.4*
34	*-0.8*	*-0.9*	*0.7*
3_01_3	*0.7*	*2.8*	*-2.8*
7865_IVP	*0.9*	*-0.2*	*1.3*
7865_MARK	*-0.6*	*-5.0*	*0.1*
PIER_EAST	*1.0*	*0.2*	*1.4*
PIER_SOUTH	*1.2*	*-0.2*	*1.0*

Table 10: Tie discrepancies between current survey and previous survey (current minus previous)

5.8 Other

At the request of the site host (Jake Griffiths), a position for a meteorological weather station was established with this survey in a single observation terrestrial occupation. These measurements are to a non-recoverable, nondescript point on the station.

Surveyed geocentric coordinates, ITRF2014 (epoch 2019/06/28)						
STATION	***X(m)***	***Y(m)***	***Z(m)***	***SX(m)***	***SY(m)***	***SZ(m)***
WEATHER	1092757.5861	-4877224.3444	3948980.8372	0.0003	0.0005	0.0006

Table 11: Coordinate estimate for weather station

6 Planning aspects

On-site contact:

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Recommendations

The NRL retro-reflectors installed on the SLR calibration piers are subject to outdoor elements such as birds, weather and heat. The reflector mounted on the Radar Tower appears to be de-laminating from the housing, causing poor signal return. NGS recommends these reflectors be replaced with new reflectors and a cover installed when not in use.

Coordinate the survey schedule with the on-site staff in advance to take advantage of non-observing periods.

7 References

7.1 Name of person(s) responsible for observations

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7.2 Name of person(s) responsible for analysis

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Phone: (540) 373-1243

7.3 Location of observation data and results archive

National Geodetic Survey
538 Front Street
Norfolk, VA 23510

Phone: (757) 441-5467
https://www.ngs.noaa.gov/corbin/iss/index.shtml

7.4 Works referenced

Fancher, Kendall (2016) National Geodetic Survey NRL Stafford Report.

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

International Laser Ranging Service. https://ilrs.cddis.eosdis.nasa.gov/