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

FOUNDATION CORS PROGRAM
TABLE MOUNTAIN GRAVITY OBSERVATORY LOCAL SITE SURVEY REPORT

Kevin Jordan
Ryan Hippenstiel
Kendall Fancher

Date of Survey: July 2019
Date of Report: October 2019

Introduction

In July 2019, the National Geodetic Survey (NGS) conducted a local tie survey at NOAA's Table Mountain Geophysical Observatory near Longmont, Colorado (USA). The site features co-located geodetic control marks, a historic NOAA CORS Network Station TMGO and a new Foundation CORS station TMG2.

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 and survey-grade GNSS instrumentation. The local relationships were aligned to the current International Terrestrial Reference Frame at the epoch date of the survey, ITRF2014 (2019/07/16). This report documents the instrumentation, observations, analysis, and results of the survey.

1 Site description

Site name: Table Mountain Gravity Observatory
Country name: United States of America
Surveying institution: National Geodetic Survey
Dates of survey: July 15 – 19, 2019
Longitude: W 105° 13'
Latitude: N 40° 07'
Tectonic plate: North American

Geodetic Technique	Name	DOMES#	ITRF Description
GNSS	TMGO	49433M001	Geometric Reference Point
GNSS	TMG2	-	Geometric Reference Point

Table 1: ITRF site information for space geodetic technique instruments

2 Instrumentation

2.1 Tacheometers, EDMI, theodolites

2.1.1 Description

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

2.1.2 Calibrations

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

2.1.3 Auxiliary equipment

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

2.1.4 Analysis software

Terrestrial observations and analysis were conducted with commercially available software Spatial Analyzer (version 2017.08.11_29326) from New River Kinematics. Least squares adjustments were conducted with commercially available software Star*Net (version 9,1,4,7868) 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: 4619K01307, 4624K01648, 4624K01590, 4624K01583
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: 12344336, 12545667, 60165452, 60125131

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.

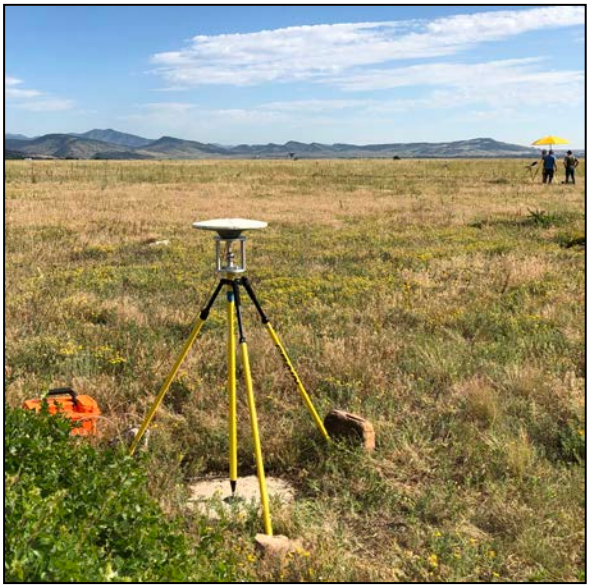
2.4 Tripods

Wooden surveying tripods with collapsible legs were used to support surveying instrumentation.

Surveying tripod for instrumentation

2.5 Forced-centering devices

Target reflectors and GNSS antennas were centered over marks using fixed-height range poles, Marksman XY-010 trivets, and adapters with known offsets.



Forced-centering device to occupy a mark

Marksman trivet with forced-centering pin

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

In addition to the two space geodetic techniques, the site has several existing ground marks which were recovered.

3.1.1 Listing

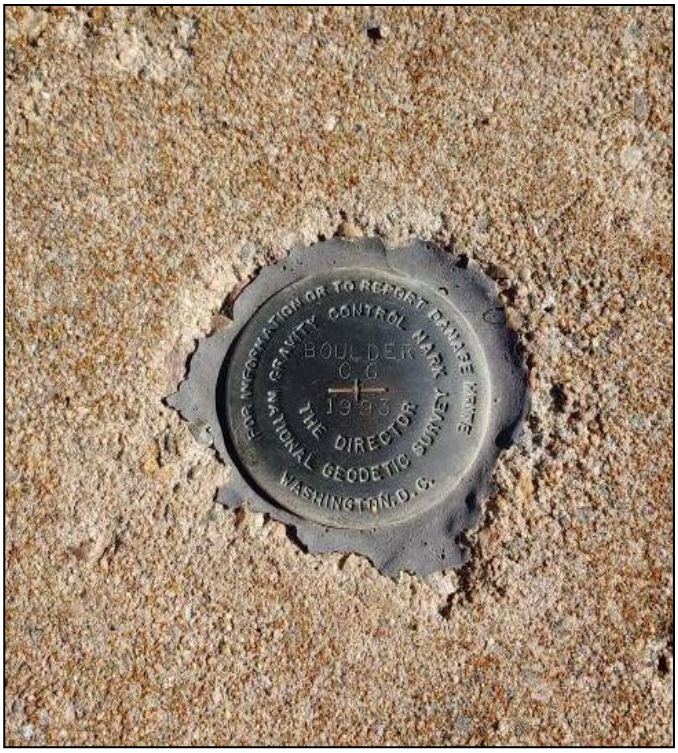
Current Survey	DOMES	IERS 4-char code	Current Survey ID	Previous Survey Point Name	NGS PID
Space geodetic technique stations					
TMGO	49433M001	n/a	TMGO	TABLE MOUNTAIN CORS MON	AF9516
TMG2	n/a	n/a	TMG2	-no previous site survey-	DQ7578
Ground Control Marks					
A TMGO	n/a	n/a	ATMG	A TMGO	AE5128
BOULDER CG	--	--	BOCG	BOULDER CG	DE5954
ECKL	--	--	ECKL	ECKL	n/a
TMGO RM 1	--	--	TMR1	TMGO RM 1	n/a
TMGO RM 2	--	--	TMR2	TMGO RM 2	n/a
WELL HEAD	--	--	WELL	WELL HEAD	n/a
Gravity Marks					
BOULDER AG	--	--	BOAG	BOULDER AG	DE5879
BOULDER AH	--	--	BOAH	BOULDER AH	DE5942
BOULDER AI	--	--	BOAJ	BOULDER AI	DE5943
BOULDER AJ	--	--	BOAJ	BOULDER AJ	DE5944
BOULDER AK	--	--	BOAK	BOULDER AK	DE5945
BOULDER AN	--	--	BOAN	BOULDER AN	DE5948
BOULDER AO	--	--	BOAO	BOULDER AO	DE5949
BOULDER AP	--	--	BOAP	BOULDER AP	DE5950
BOULDER AQ	--	--	BOAQ	BOULDER AQ	DE5951
BOULDER AS	--	--	BOAS	BOULDER AS	--
BOULDER AT	--	--	BOAT	BOULDER AT	--

Table 2: Listing of SGT stations and ground network marks

Ground network mark descriptions

A TMGO (ATMG) The station is a forced-centering pier with a 5/8-11 threaded stud projecting from a metal plate stamped---A TMGO 1995--- atop a 50 cm (18”) in diameter concrete pier encased in a PVC pipe projecting 1.5 m (60”) above the ground, located inside four wooden posts 62.5 m (205’) NE of the NE end of Bldg. F-6.

BOULDER CG (BOCG) The station is a NGS gravity disk stamped---BOULDER CG 1993---, set in a square concrete pad, 1.5 m (5’) on side and flush with the ground, located on the easterly side of the TMGO office building, 8.5 m (28’) SSE of the ENE corner and 9 m (30’) NE of the SSE corner.

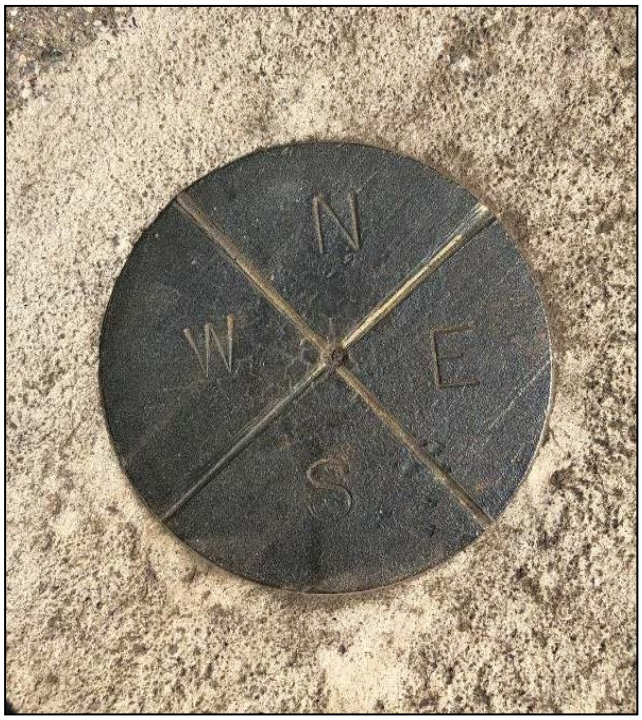


ECKL (ECKL) The station is a NGS gravity disk stamped---ECKL 2014---, set in the top of a concrete post flush with the ground, located 9 m (30') NW of the center of the driveway to the TMGO parking lot, 9.3 m (30.5') SW of the SW corner of the parking lot and 2.4 m (8') west of the SW corner of the parking lot and 2.4 m (8') west of the SW corner of a concrete pad, 3 m X 7 m (10' X 24')

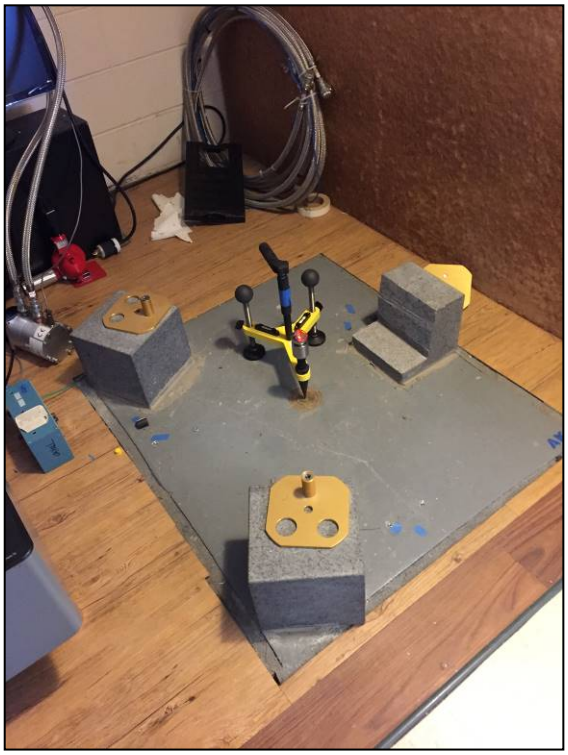
TMGO RM 1 (TMR1) The station is a NGS reference mark disk stamped---TMGO NO 1 2014---, set in the top of a concrete post flush with the ground, located 17 m (55') WNW of the N corner of the TMGO parking lot, 28 m (93') NW of the north corner of Bldg. F-6, and 1.7 m (5.5') SSW of a drainage ditch.

TMGO RM 2 (TMR2) The station is a NGS reference mark disk stamped---TMGO NO 2 2014---, set in the top of a concrete post flush with the ground, located near a propane tank on the SE side of Bldg. F-6, 3.5 m (12') east of the center of the tank, 10 m (33') SE of the east corner of the building and 14 m (47') ENE of the south corner of the building.

WELL HEAD (WELL) The station is a NGS survey disk stamped---N E S W---, set in a 1.7 m X 3.4 m (5' X 11') concrete pad between two well heads, located near a wooden shed at the east corner of the TMGO parking lot, 3.7 m (12') NW of the parking lot corner, 5.5 m (18') west of the north corner the shed and 11 m (36') NE of the NE entrance to Bldg.



BOULDER AK (BOAK) The station is a NGS gravity disk stamped---BOULDER AK 1993---, set in the top center of a rectangular concrete post 85 cm X 100 cm (34” X 40”) flush with the floor inside the superconducting gravimeter (SG) enclosure inside Bldg. F-6. Currently, the SC gravimeter is decommissioned and was removed at the time of survey.

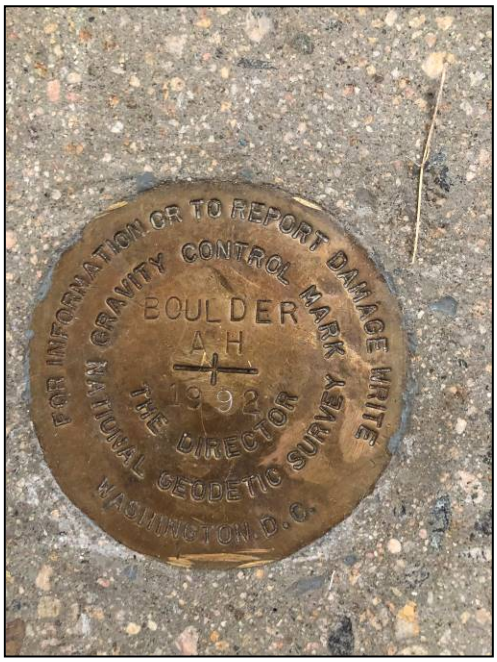


Decommissioned SC Gravimeter

Additional gravity marks

BOULDER AG (BOAG) The station is a NGS gravity disk stamped---BOULDER AG 1993---, set in the top center of a rectangular concrete post 53 cm X 64 cm (21” X 25”) flush with the floor inside Bldg. F-6.

BOULDER AH (BOAH) The station is a NGS gravity disk stamped---BOULDER AH 1993---, set in the top center of a rectangular concrete post 53 cm X 64 cm (21” X 25”) flush with the floor inside Bldg. F-6.

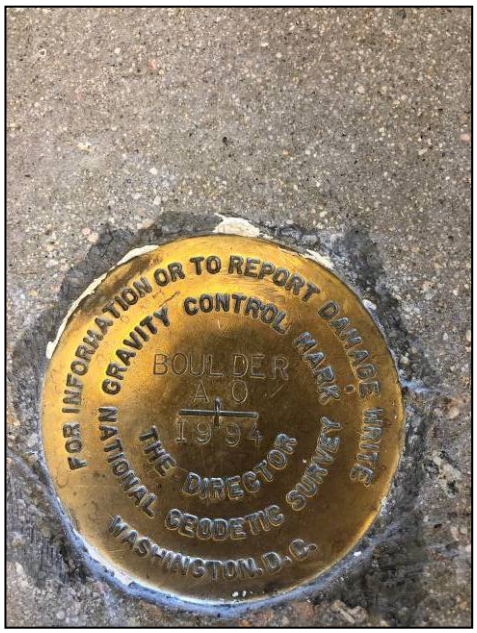


BOULDER AI (BOAI) The station is a NGS gravity disk stamped---BOULDER AI 1993---, set in the top center of a rectangular concrete post 85 cm X 100 cm (34” X 40”) flush with the floor inside Bldg. F-6.

BOULDER AJ (BOAJ) The station is a NGS gravity disk stamped---BOULDER AJ 1993---, set in the top center of a rectangular concrete post 91 cm X 107 cm (36” X 42”) flush with the floor inside Bldg. F-6.

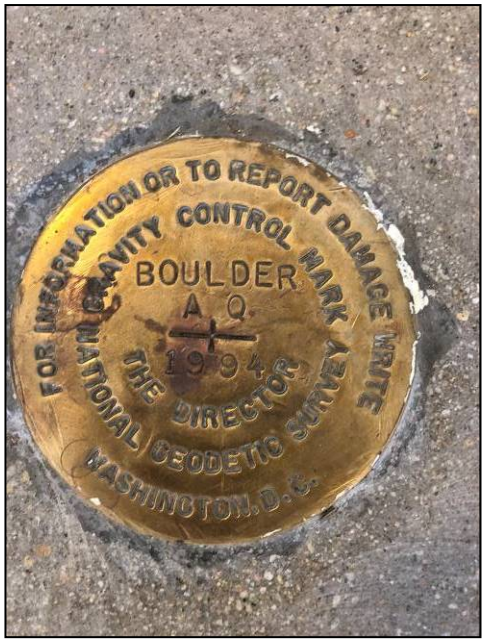
BOULDER AN (BOAN) The station is a NGS gravity disk stamped---BOULDER AN 1994---, set in the top center of a rectangular concrete post 56 cm X 56 cm (22” X 22”) flush with the floor inside Bldg. F-6.

BOULDER AO (BOAO) The station is a NGS gravity disk stamped---BOULDER AO 1994---, set in the top center of a rectangular concrete post 56 cm X 56 cm (22” X 22”) flush with the floor inside Bldg. F-6.



BOULDER AP (BOAP) The station is a NGS gravity disk stamped---BOULDER AP 1994---, set in the top center of a rectangular concrete post 56 cm X 56 cm (22” X 22”) flush with the floor inside Bldg. F-6.

BOULDER AQ (BOAQ) The station is a NGS gravity disk stamped---BOULDER AQ 1994---, set in the top center of a rectangular concrete post 87 cm X 87 cm (34” X 34”) flush with the floor inside Bldg. F-6.



BOULDER AS (BOAS) The station is a NGS gravity disk stamped---BOULDER AS 2010---, set in the top center of a rectangular concrete post 56 cm X 56 cm (22” X 22”) flush with the floor inside Bldg. F-6.

BOULDER AT (BOAT) The station is a NGS gravity disk stamped---BOULDER AT 2010---, set in the top center of a rectangular concrete post 56 cm X 56 cm (22” X 22”) flush with the floor inside Bldg. F-6.

3.1.2 Map of network

Control stations at Table Mountain Gravity Observatory

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

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

3.2.3 GNSS

TMGO The station is a forced-centering antenna mount atop a 6 m (20') steel tower with bracing about halfway up the tower anchoring it to Bldg. F-6. A 5/8-11 stud protrudes through a 15 cm (6")

diameter steel plate. An indirect approach as discussed later in Section 4.3, was used to determine position of the Geometric Reference Point (GRP) in the survey, as the antenna was not removed.

TMGO atop steel tower

TMG2 The GRP is represented by a divot in a SCIGN antenna mount, affixed to the top of a deep drill braced monument. TMG2 is occupied by a choke ring antenna, JAVRINGANT_DM with SCIS 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. An indirect approach as discussed later in Section 4.3, was used to determine position of the Geometric Reference Point (GRP) in the survey, as the antenna was not removed.

TMG2

3.2.4 DORIS

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

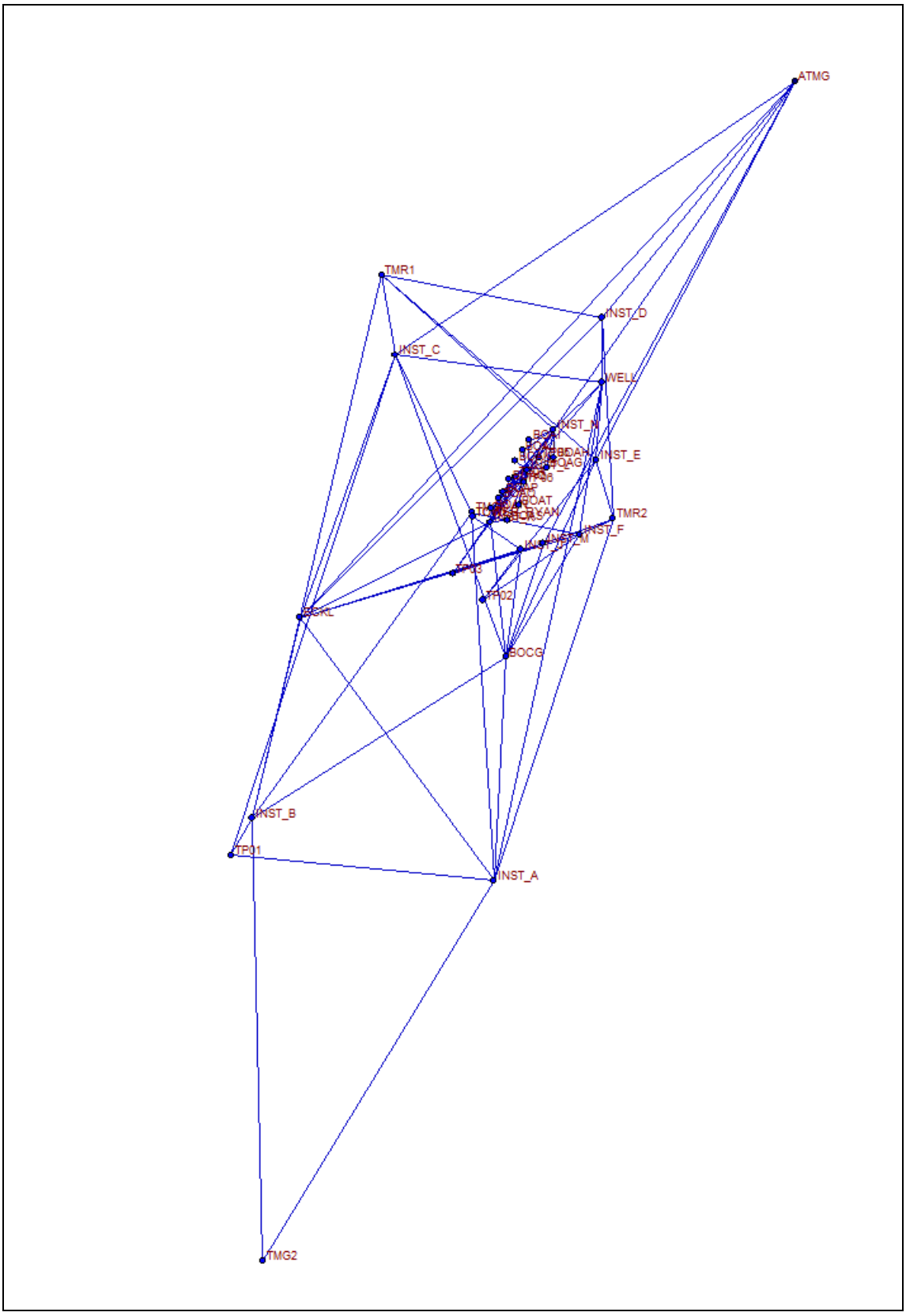
4 Observations

4.1 Terrestrial survey

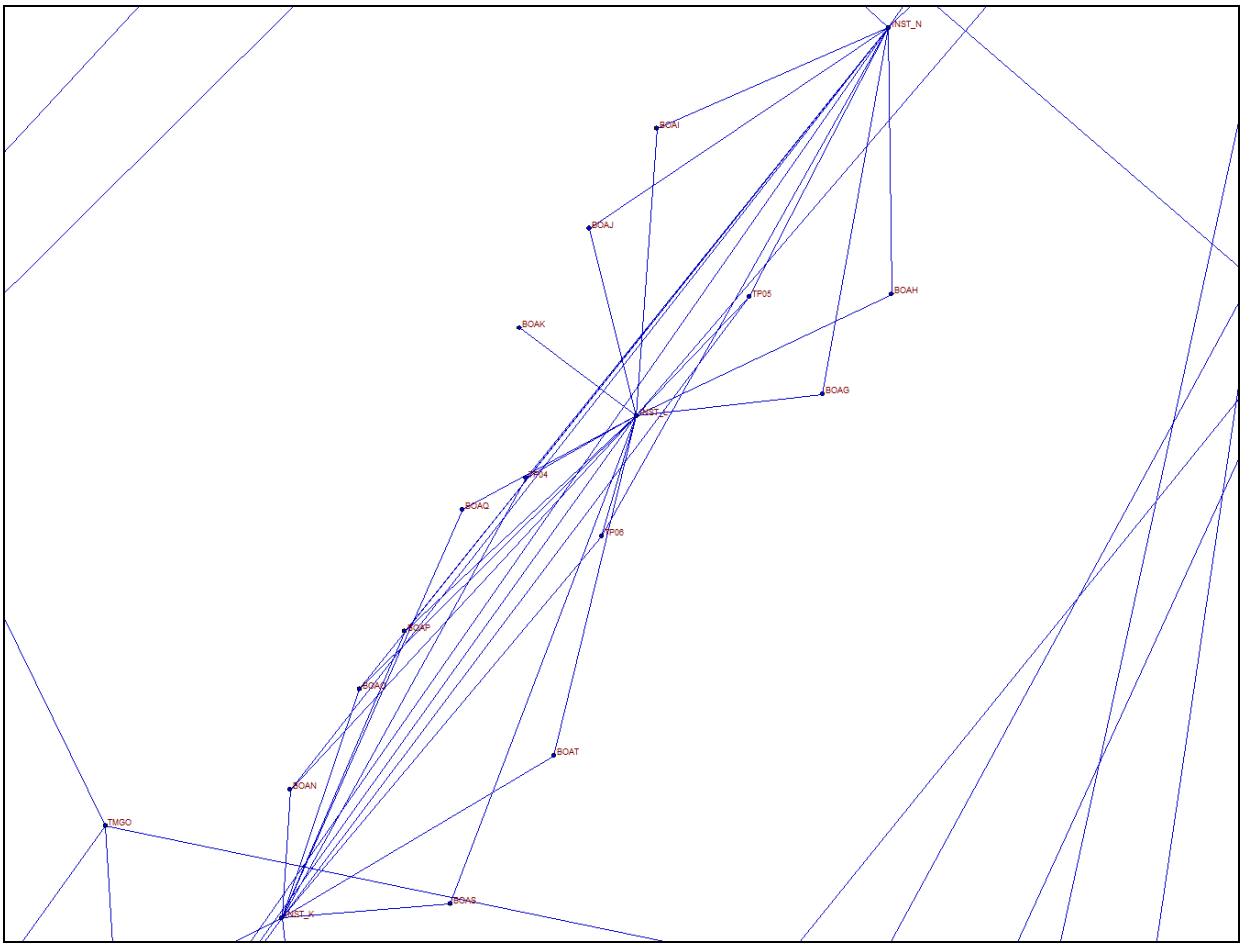
The terrestrial survey was completed using an absolute laser tracker system. The instrument measured horizontal angles, vertical angles, and distances to retro-reflector targets which were used to position the marks and techniques. GNSS observations were also collected to support the terrestrial survey.

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.

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



Network stations at Table Mountain Gravity Observatory



Detail of observing scheme for gravity marks inside Bldg.

Vertical offsets of terrestrial survey stations (units in meters)

STATION	OFFSET 1	OFFSET 2	PRISM	TOTAL OFFSET
TMGO (Bottom of pre-amp)	Reported Marker-ARP Ecc. 0.0000	Leica Nest Bottom Plate 0.0099	Leica Nest with Prism (inverted) -0.0550	-0.0451
TMG2	Reported Marker-ARP Ecc. 0.0083	Bottom of Antenna to ARP 0.0345	Leica Nest with Prism (inverted) -0.0550	-0.0122
ATMG		MTA B, Bottom Plate 0.0098	Leica Nest with Prism 0.0550	0.0648
ECKL	Rod B 1.0422	MTA A, Bottom Plate 0.0098	Leica Nest with Prism 0.0550	1.1070
BOCG	Rod A 1.0426	MTA C, Bottom Plate 0.0098	Leica Nest with Prism 0.0550	1.1074
TMR1	Rod D 1.0426	MTA D, Bottom Plate 0.0098	Leica Nest with Prism 0.0550	1.1074

TMR2	Rod C 1.0425		Brunson Nest with Prism 0.0526	1.0951
WELL		Marksman B 0.1660	Brunson Nest w/Prism (recessed) 0.0511	0.2171
BOAP (INST_K)		Marksman B 0.1660	BR -RECESS 0.0511	0.2171
BOAO (INST_K)		Marksman B 0.1660	BR -RECESS 0.0511	0.2171
BOAQ (INST_K)		Marksman A 0.1660	BR -RECESS 0.0511	0.2171
BOAN (INST_K)		Marksman A 0.1660	BR -RECESS 0.0511	0.2171
BOAT (INST_K)		Marksman C 0.1662	BR -RECESS 0.0511	0.2173
BOAS (INST_K)		Marksman C 0.1662	BR -RECESS 0.0511	0.2173
BOAI (INST_L)		Marksman A 0.1660	BR -RECESS 0.0511	0.2171
BOAH (INST_L)		Marksman B 0.1660	BR -RECESS 0.0511	0.2171
BOAJ (INST_L)		Marksman A 0.1660	BR -RECESS 0.0511	0.2171
BOAG (INST_L)		Marksman B 0.1660	BR -RECESS 0.0511	0.2171
BOAP (INST_L)		Marksman B 0.1660	BR -RECESS 0.0511	0.2171
BOAO (INST_L)		Marksman B 0.1660	BR -RECESS 0.0511	0.2171
BOAQ (INST_L)		Marksman A 0.1660	BR -RECESS 0.0511	0.2171
BOAN (INST_L)		Marksman B 0.1660	BR -RECESS 0.0511	0.2171
BOAT (INST_L)		Marksman A 0.1660	BR -RECESS 0.0511	0.2171
BOAS (INST_L)		Marksman A 0.1660	BR -RECESS 0.0511	0.2171
BOAK (INST_L)		Marksman C 0.1662	BR -RECESS 0.0511	0.2173
BOAI (INST_N)		Marksman C 0.1662	BR -RECESS 0.0511	0.2173

BOAH (INST_N)		Marksman A 0.1660	BR -RECESS 0.0511	0.2171
BOAH (INST_N) (SET 10-12)		Marksman C 0.1662	BR -RECESS 0.0511	0.2173
BOAJ (INST_N)		Marksman C 0.1662	BR -RECESS 0.0511	0.2173
BOAG (INST_N)		Marksman A 0.1660	BR -RECESS 0.0511	0.2171
BOAP (INST_N)		Marksman C 0.1662	BR -RECESS 0.0511	0.2173
BOAO (INST_N)		Marksman A 0.1660	BR -RECESS 0.0511	0.2171
BOAN (INST_N)		Marksman A 0.1660	BR -RECESS 0.0511	0.2171
ATMG (INST_M) (LINE OF SIGHT)		MTA B, Bottom Plate 0.1507	Leica Nest with Prism 0.0550	0.2057
ATMG (INST_N) (LINE OF SIGHT)		MTA B, Bottom Plate 0.1507	Leica Nest with Prism 0.0550	0.2057

Table 3

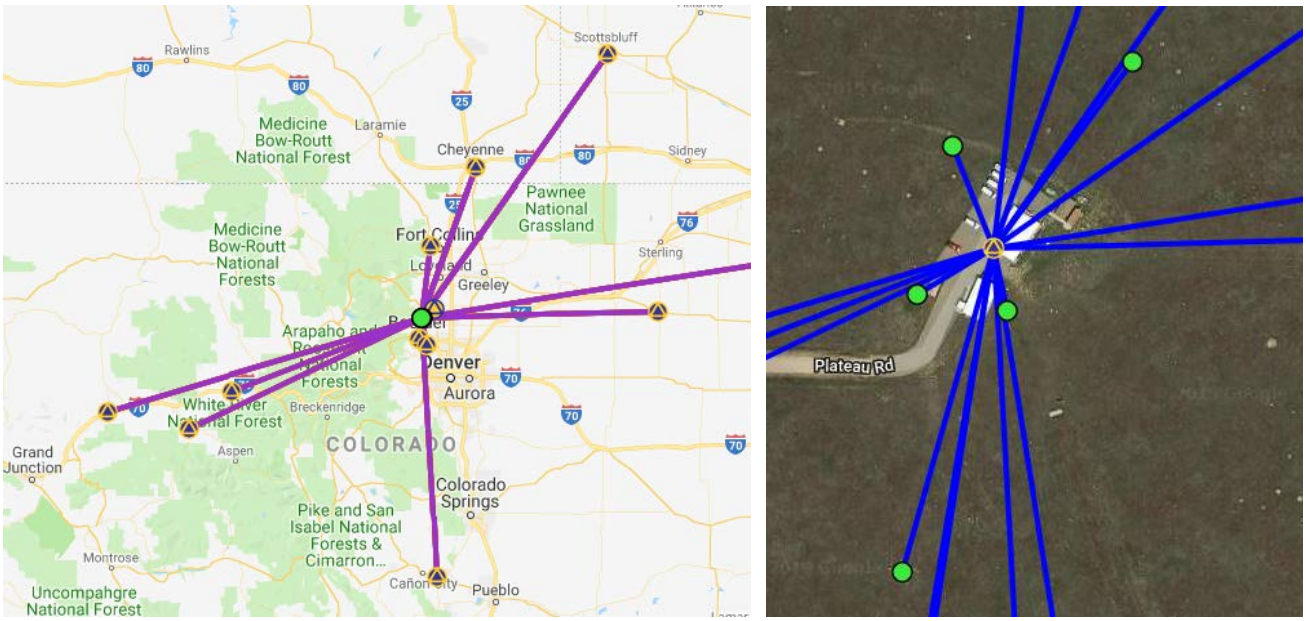
4.2 Leveling

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. Over multiple days, simultaneous long-session (20+ hour) observations were taken at several stations. Publicly available observation data was also obtained for CORS in the region.

GNSS observations were processed with a minimally constrained, “hub” design emanating from NGS tracking station TMGO. 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

Vertical offsets of GNSS survey stations (units in meters)

STATION	OFFSET 1	OFFSET 2	TOTAL OFFSET
ATMG	0.0000	MTA B, Overall 0.1507	0.1507
ECKL	Rod B 1.0422	MTA A, Overall 0.1506	1.1928
BOCG	Rod A 1.0426	MTA C, Overall 0.1507	1.1933
TMR1	Rod D 1.0426	MTA D, Overall 0.1507	1.1933
TMG2	Reported Ecc. 0.0083		0.0083
TMGO	Reported Ecc. 0.0000		0.0000

Table 4

4.4 General comments

Resection method for terrestrial observations

In the terrestrial survey, the resection principle was employed to measure between network stations 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 stations. At each instrument occupation, a series of measurements were taken to the surrounding visible stations. By observing common features from different instrument occupations, the relative positions of both the instrument and targets were established.

The resection procedure was chosen to take advantage of the laser tracker's high-precision capabilities and mitigate setup errors. By setting up at arbitrary points rather than occupying the marks, horizontal and vertical centering errors were statistically insignificant. While the vectors between stations were not

observed directly, the measurements were precise enough to determine relative positions with at the sub-millimeter level.

Establishing points via circle-fitting

Coordinates of the GNSS stations TMGO and TMG2 GRP were determined using an indirect approach. 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.

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.

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

Surveyed topocentric coordinates, ITRF2014 (epoch 2019/07/17)						
STATION	***E(m)***	***N(m)***	***U(m)***	***SE(m)***	***SN(m)***	***SU(m)***
Space geodetic technique stations						
TMGO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
TMG2	-30.3735	-108.3002	-3.8646	0.0008	0.0004	0.0005
Ground network marks						
ATMG	47.1090	62.3844	-6.1625	0.0006	0.0004	0.0002
BOAG	10.8834	6.4957	-6.2936	0.0002	0.0002	0.0001
BOAH	11.9345	7.9972	-6.2956	0.0002	0.0002	0.0001
BOAI	8.3582	10.4684	-6.2862	0.0002	0.0002	0.0001
BOAJ	7.3312	8.9700	-6.2917	0.0002	0.0002	0.0001
BOAK	6.2763	7.4765	-6.2765	0.0002	0.0002	0.0002
BOAN	2.8083	0.5476	-6.2695	0.0002	0.0002	0.0001
BOAO	3.8600	2.0558	-6.2702	0.0002	0.0002	0.0001
BOAP	4.5429	2.9271	-6.2693	0.0002	0.0002	0.0001
BOAQ	5.4181	4.7505	-6.2721	0.0002	0.0002	0.0001
BOAS	5.2471	-1.1573	-6.2734	0.0002	0.0002	0.0001

BOAT	6.8148	1.0661	-6.2758	0.0002	0.0002	0.0001
BOCG	5.0129	-20.8766	-6.4991	0.0003	0.0002	0.0001
ECKL	-25.1479	-15.2548	-6.2693	0.0002	0.0003	0.0002
TMR1	-13.3373	34.2618	-6.6860	0.0003	0.0002	0.0002
TMR2	20.6645	-0.8414	-6.7187	0.0002	0.0002	0.0001
WELL	18.9935	18.8400	-6.7648	0.0002	0.0002	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 2019/07/17)						
STATION	***X(m)***	***Y(m)***	***Z(m)***	***SX(m)***	***SY(m)***	***SZ(m)***
Space geodetic technique stations						
TMGO	-1283387.9785	-4713015.4277	4090190.2763	0.0000	0.0000	0.0000
TMG2	-1283434.8487	-4713071.9474	4090104.9819	0.0008	0.0005	0.0004
Ground network marks						
ATMG	-1283330.7221	-4712984.4627	4090234.0018	0.0005	0.0004	0.0003
BOAG	-1283375.1132	-4713009.6047	4090191.1863	0.0002	0.0002	0.0002
BOAH	-1283373.8443	-4713008.9457	4090192.3330	0.0002	0.0002	0.0002
BOAI	-1283376.8784	-4713006.4761	4090194.2285	0.0002	0.0002	0.0002
BOAJ	-1283378.1219	-4713007.1341	4090193.0793	0.0002	0.0002	0.0002
BOAK	-1283379.3957	-4713007.7969	4090191.9472	0.0002	0.0002	0.0002
BOAN	-1283383.9167	-4713011.1999	4090186.6541	0.0002	0.0002	0.0002
BOAO	-1283382.6464	-4713010.5378	4090187.8068	0.0002	0.0002	0.0002
BOAP	-1283381.8401	-4713010.1760	4090188.4735	0.0002	0.0002	0.0002
BOAQ	-1283380.6863	-4713009.2700	4090189.8658	0.0002	0.0002	0.0002

BOAS	-1283381.8515	-4713012.8981	4090185.3480	0.0002	0.0002	0.0002
BOAT	-1283379.9619	-4713011.9255	4090187.0464	0.0002	0.0002	0.0002
BOCG	-1283385.3715	-4713024.9333	4090170.1257	0.0003	0.0002	0.0002
ECKL	-1283413.5668	-4713013.6822	4090174.5721	0.0002	0.0002	0.0002
TMR1	-1283393.7020	-4712985.6840	4090212.1626	0.0003	0.0002	0.0002
TMR2	-1283366.8328	-4713016.4239	4090185.3026	0.0002	0.0002	0.0002
WELL	-1283365.1029	-4713003.7112	4090200.3207	0.0002	0.0002	0.0002

Table 6: Coordinate estimates for network stations

5.3 Additional parameters

No additional parameters.

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 the ***.SNX*** SINEX file ***NGSTMGO1907.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              =      6

               Number of Stations      =     49

               Number of Observations  =   1613
               Number of Unknowns      =    211
               Number of Redundant Obs =   1402

   Observation   Count   Sum Squares         Error
                           of StdRes        Factor
   Coordinates       3         0.000         0.000
    Directions     420       356.923         0.989
     Distances     426       349.222         0.971
       Zeniths     425       348.495         0.971
    GPS Deltas     339       292.858         0.997

         Total    1613      1347.498         0.980

         The Chi-Square Test at 5.00% Level Passed
              Lower/Upper Bounds (0.963/1.037)
```

Comparison with IERS computed tie
No comparison possible.

5.7 Comparison with previous surveys

A previous survey was carried out at the site by the National Geodetic Survey, with field observations in 2015. As a check on the results of the current survey, Star*Net software was used to align the current survey to the previous survey in the ITRF2008 reference frame. 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 (NGS 2015) Topocentric tie discrepancies			
STATION	***DE (mm)***	***DN (mm)***	***DU (mm)***
ATMG	0.0	0.0	0.0
BOAG	0.9	0.7	-3.3
BOAH	-0.3	0.9	-2.9
BOAI	1.2	-1.4	-3.3
BOAJ	0.9	-2.2	-3.3
BOAK	59.6	-31.7	19.3
BOAN	0.5	-1.6	-3.5
BOAO	-0.2	0.3	-3.6
BOAP	0.8	0.9	-3.6
BOAQ	-8.6	0.0	-3.6
BOAS	0.9	-0.1	-3.5
BOAT	0.1	1.5	-3.3
BOCG	2.0	0.7	-4.4

ECKL	-0.3	-1.0	-8.1
TMGO	-0.3	0.9	-3.2
TMR1	-2.6	-2.0	-7.1
TMR2	-0.5	-0.4	-3.9
WELL	0.7	0.8	-4.4

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

6 Planning aspects

Contact Information

Van Westrum, Derek Colby PhD
325 Broadway
Building: DSRC
Boulder, CO 80305
Email: derek.vanwestrum@noaa.gov
Government Cell Phone: 240-988-6341

On-site contact:
Coloma, Francine
325 Broadway
Building: DSRC
Boulder, CO 80305
Email: Francine.coloma@noaa.gov
Phone: 303-497-3692

Contact for previous surveys and data:
National Geodetic Survey
Instrumentation & Methodologies Branch
15351 Office Drive
Woodford, VA 22580
Phone: 540-373-1243

Recommendations

The TMGO CORS is slated to be decommissioned. Recommendation is to keep the current tower and antenna configuration as long as possible for use in future surveys.

Prior to future surveys, it is recommended to install additional ground control marks near TMG2 to improve control network.

Watch out for snakes on sunny, warm days.

GNSS data collection can be affected by birds in the area. Always check tripod setups.

7 References

7.1 Name of person(s) responsible for observations

Kevin Jordan (Kevin.Jordan@noaa.gov)
Ryan Hippenstiel (Ryan.Hippenstiel@noaa.gov)
Kendall Fancher (Kendall.Fancher@noaa.gov)

National Geodetic Survey
538 Front Street
Norfolk, VA 23510
Phone: (757) 441-5467

7.2 Name of person(s) responsible for analysis

Kevin Jordan (Kevin.Jordan@noaa.gov)
Benjamin Erickson (Benjamin.Erickson@noaa.gov)

National Geodetic Survey
538 Front Street
Norfolk, VA 23510
Phone: (757) 441-5467

7.3 Location of observation data and results archive

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

7.4 Works referenced

National Geodetic Survey. Table Mountain Report (2015).
https://www.ngs.noaa.gov/corbin/iss/index.shtml

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