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

FOUNDATION CORS PROGRAM
LOCAL SITE SURVEY REPORT
MAUI, HAWAII, USA

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Date of Survey: March 2019
Date of Report: June 2019

Introduction

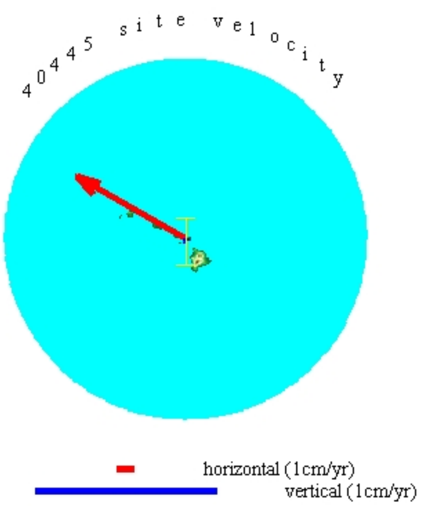
In March 2019, the National Geodetic Survey (NGS) conducted a local tie survey at the Haleakala Observatory. The observatory is an International Earth Rotation and Reference Systems Service (IERS) site, designated Maui, located on the Island of Maui, Hawaii, USA. The site features co-located space geodetic technique (SGT) instruments that contribute to realizations of the International Terrestrial Reference Frame (ITRF).

Space geodetic techniques at the site include Satellite Laser Ranging (SLR) and Global Navigation Satellite Systems (GNSS). GNSS stations MAUI and HAL1 are International GNSS Service (IGS) tracking network stations and NGS Continuously Operating Reference Stations (CORS). One of these stations will be 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, ITRF2014 (2019/03/11). This report documents the instrumentation, observations, analysis, and results of the survey.

1 Site description

IERS site name: Maui
IERS site number: 40445
Country name: United States of America
Surveying institution: National Geodetic Survey
Dates of survey: March 6 - 16, 2019
Longitude: W 156° 16’
Latitude: N 20° 43’
Tectonic plate: Pacific



SGT Technique	Name	DOMES#	ITRF Description
GNSS	HAL1	40445M006	Reference point of a SCIGN antenna mount on short (1m) concrete pillar.
GNSS	MAO0	40445M005	Reference point of a forced antenna device fixed on top of a pyramidal steel mast.
GNSS	MAUI	40445S008	Ashtech Dorne-Margolin chokering antenna. ARP center of base of pre-amplifier.
SLR	7119	40445M004	Marker under SLR telescope on the summit of Haleakala.
SLR	7119	40445S009	Permanent SLR instrument - intersection of axes.

Table 1: ITFR site information for space geodetic technique instruments

2 Instrumentation

2.1 Tacheometers, EDMI, theodolites

2.1.1 Description

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

Leica TDM5005, S/N: 441698 (total station)
Specifications:
Angular measurement uncertainty: +/- 0.7"
Distance standard deviation of a single measurement: 1 mm + 2 ppm

2.1.2 Calibrations

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

Leica TDM5005, S/N 441698: originally calibrated by Leica Geosystem AG Heerbrugg, Switzerland (inspection date 2008/08/20). In April, 2016 this instrument's EDMI was evaluated using the NGS Corbin Calibration Baseline and found to be measuring distances within the manufacturer's specifications.

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, 4624K01615, 4624K01647
Specifications for Static GPS Surveying:
Horizontal: +/- 5 mm + 0.5 ppm RMS
Vertical: +/- 5 mm + 1 ppm RMS

2.2.2 Antennas

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

2.2.3 Analysis software

Data processing and analysis were conducted with NGS's Online Positioning User Service (OPUS) and 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

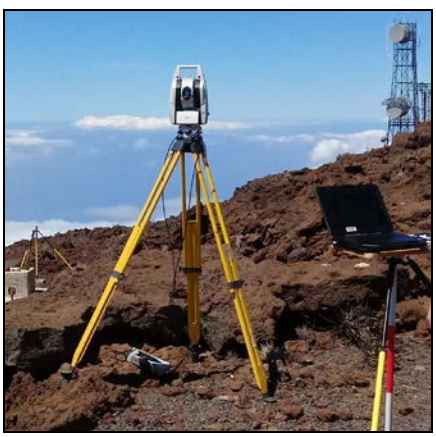
Not applicable.

2.3.3 Checks carried out before measurements

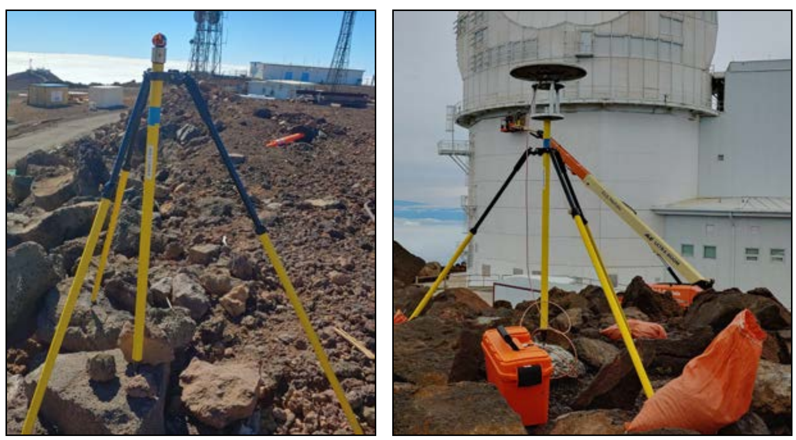
Not applicable.

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 and GNSS antennas.



Surveying tripod for instrumentation



Fixed-height range poles for reflectors and GNSS antennas

2.5 Forced-centering devices

Target reflectors and GNSS antennas were centered over marks using fixed-height range poles, a Kern trivet, and adapters with known offsets. Range poles were verified to be straight and were plumbed over the mark with a precision bubble level. For station CAL PIER A, a metal plate with protruding threaded rod was affixed to the top of a concrete pier. The threaded rod served as a forced-centering device.


Forced-centering device to occupy a mark


Kern trivet with forced-centering pin


CAL PIER A


Reflector occupying CAL PIER A

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. Non-monumented temporary points were also established to facilitate the survey. SLR telescope 7119 has an associated ground mark beneath the instrument, but it could not be accessed for this survey. The reference points for the GNSS stations were also inaccessible. Each space geodetic technique's reference point was observed and determined indirectly.

A previous survey of the site was conducted in 2013 by Troy Carpenter of Strategic Services Reston, Inc. The current survey included 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				
7119 MARK	40445M004	7119	T4 DISK	--
7119 IVP	40445S009	7119	TLRS-4	--
HAL1	40445M006	HAL1	--	--
MAO0	40445M005	MAO0	--	--
MAUI	40445S008	MAUI	GPS MAUI	AJ8470
HAL2	--	--	--	--
Ground network marks				
CAL PIER A	--	--	CAL PIER A	--
KOLEKOLE	--	--	KOLE KOLE 1950 USC&GS	TU2862
T4 RM1	--	--	T4 RM1	--
T4 RM2	--	--	--	--
T4 RM3	--	--	T4 RM3	--
UH HIG5	--	--	UH HIG	--

Table 2: Listing of SGT stations and ground network marks

Ground network mark descriptions

CAL PIER A is a forced-centering device (a threaded rod, as described above) mounted in the top of a concrete pier. The datum point is an intangible point coincident with the top center of the device. No stamping. See Forced-Centering Devices section above.

KOLEKOLE is a US Coast & Geodetic survey disk, stamped KOLEKOLE 1950, set in top of a concrete monument.

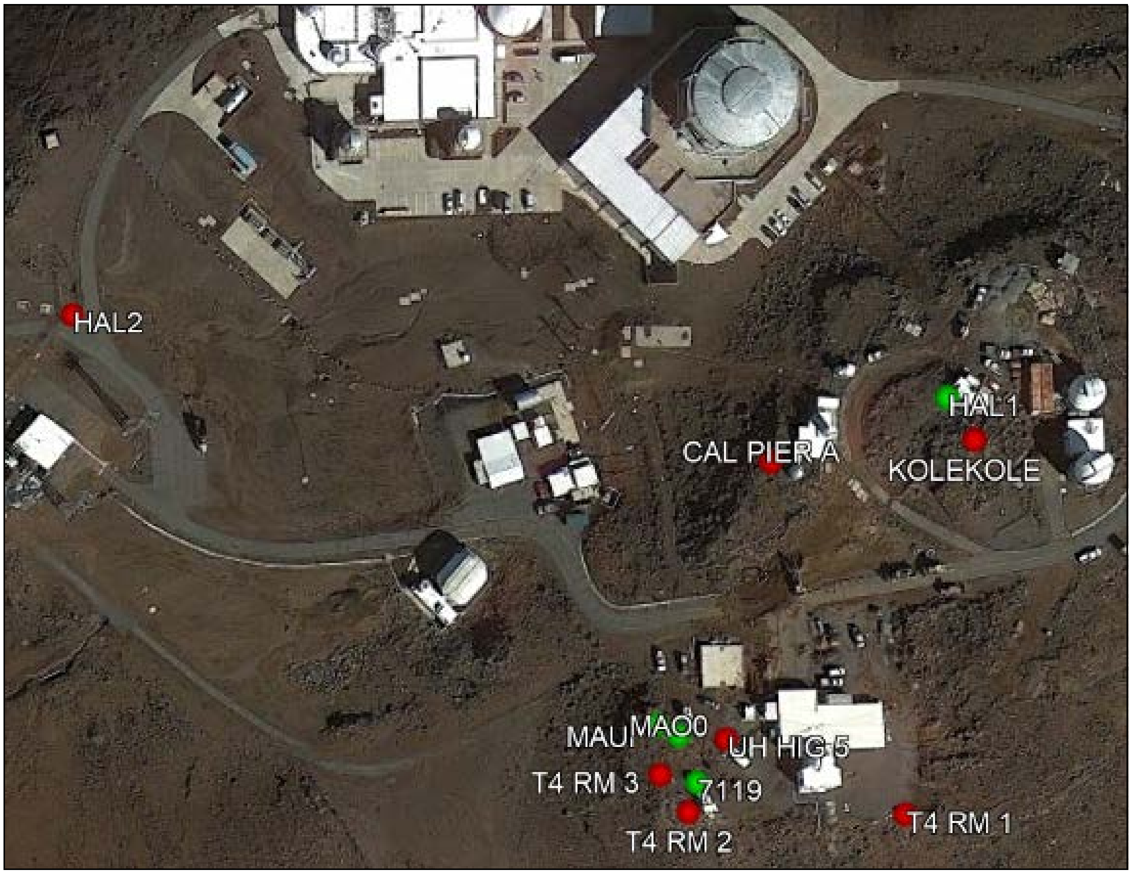
T4 RM1 is a NASA survey disk, stamped T4 RM1, set in top of a concrete monument. At the time of the survey, the mark was occupied by a Tech2000 GNSS antenna mast and GNSS antenna. Per correspondence with NASA, the GNSS station name is MAUX and had been inactive since 2016.

T4 RM2 is a survey disk with no stamping, set in top of a square concrete monument.

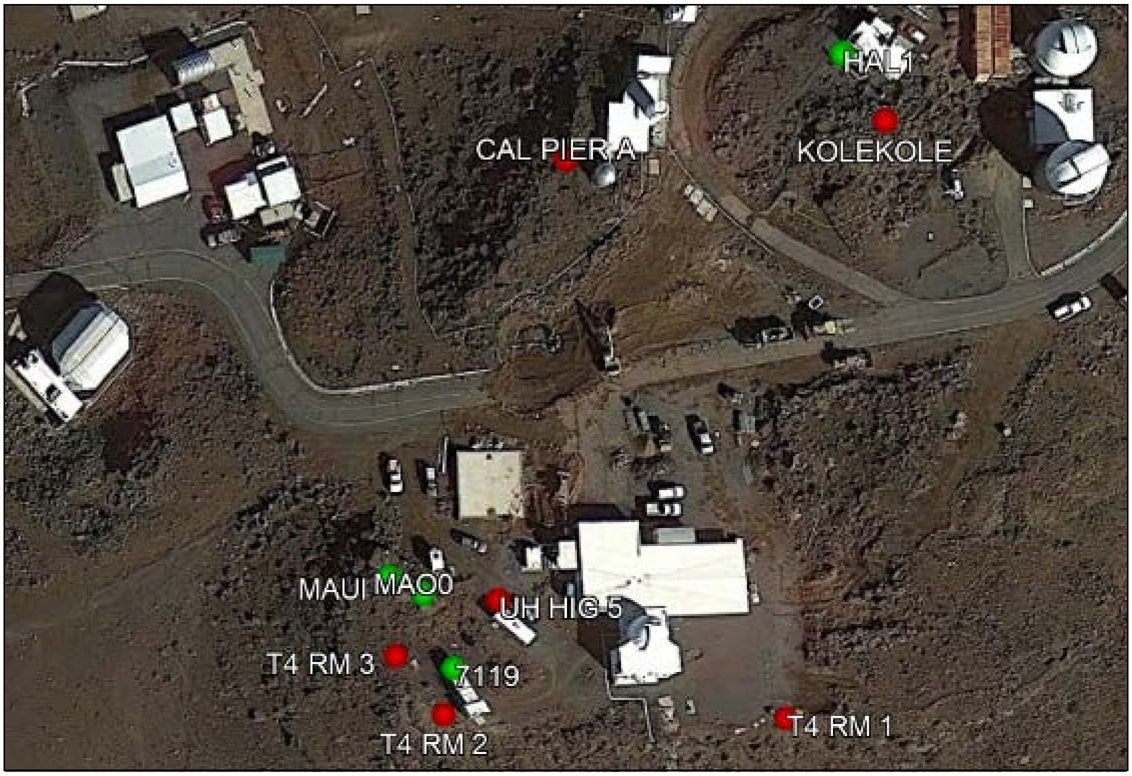
T4 RM3 is a survey disk with no stamping, set in top of a square concrete monument.

UH HIG5 is a survey disk, stamped UH.HIG. 5, set in a concrete footer slab.

3.1.2 Map of network



Surveyed stations at Haleakala Observatory



ITRF and ground network stations around the SLR telescope

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

7119 is an SLR telescope, represented by a theoretical point in space: the invariant point (IVP) about which the azimuth and elevation axes rotate. The invariant point is also known as the conventional reference point or technique reference point. Instrument 7119 is also known as TLRS-4 and HA4T.

7119 is also represented by a survey disk set in a concrete footer pad beneath the instrument. The mark was not able to be occupied and surveyed as part of this project, but per the station site log, the instrument's invariant point is eccentric from the mark by 0.003 m North, 0.003 m East, and 2.630 m Up. To distinguish between the SLR instrument and ground mark, the two points are herein identified as 7119 IVP and 7119 MARK.

SLR telescope 7119

3.2.3 GNSS

The site hosts four active GNSS technique stations, three of which are recognized by the International Terrestrial Reference System. An indirect approach was used to determine positions of the GNSS reference points in the survey, as the antennas were not removed.

HAL1 is an IGS tracking station, represented by the divot in a SCIGN antenna mount on top of a concrete pillar on a concrete building roof. HAL1 is occupied by a choke ring antenna, Javad JAVRINGANT_DM with SCIS radome. Per the site log, the ARP is eccentric from the mark by 0.0 m East, 0.0 m North, and 0.0083 m Up.

HAL2 is represented by the divot in a SCIGN antenna mount on top of a shallow-drilled brace monument. HAL2 is occupied by a choke ring antenna, Javad JAVRINGANT_DM. Based on the type of antenna mount used, the ARP is assumed to be eccentric from the mark by 0.0 m East, 0.0 m North, and 0.0083 m Up.

HAL1

HAL2

MAO0 is a represented by the reference point of the antenna mount on top of a pyramidal steel mast. MAO0 is occupied by Leica antenna LEIAR25.R3 with LEIT radome. Per the site log, the ARP is coincident with the mark.

MAUI is an IGS tracking station, represented by the top-center of a steel coupler device atop a steel mast anchored in bedrock. It is occupied by Ashtech antenna ASH700936D_M with SNOW radome. Per the site log, the ARP is coincident with the mark. For this survey, MAUI is the site marker.

MAO0

MAUI

3.2.4 DORIS

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

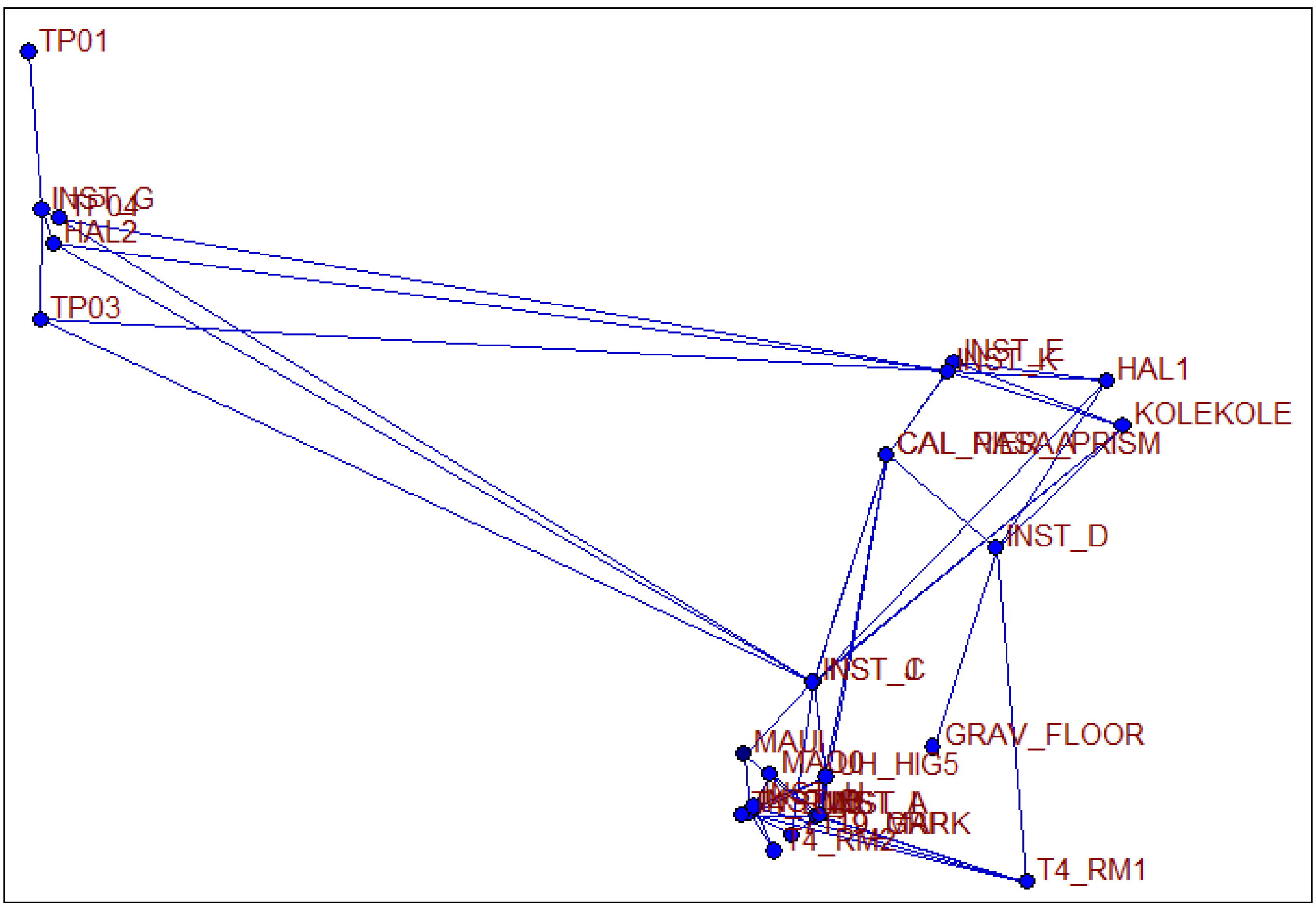
4 Observations

4.1 Terrestrial survey

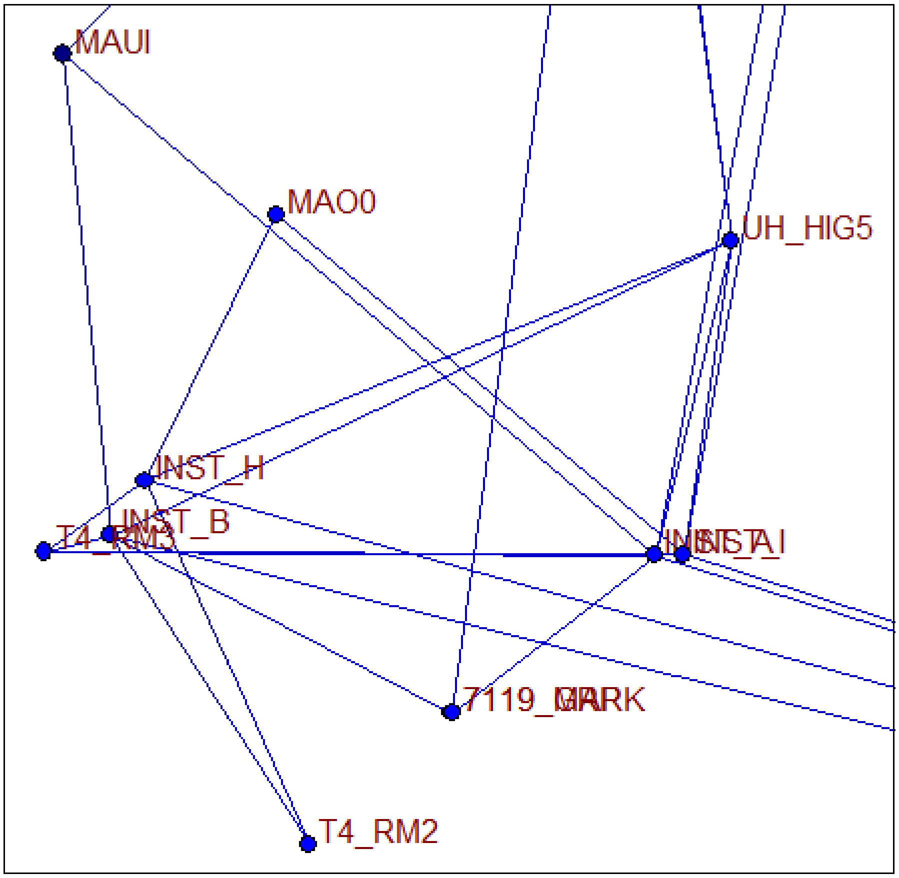
The terrestrial survey was completed using an absolute laser tracker system and a total station system. The instruments measured horizontal angles, vertical angles, and distances to retro-reflector targets which were used to position the marks and techniques. GNSS observations were also collected to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



Network stations near SLR telescope 7119

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

STATION	OFFSET 1	OFFSET 2	PRISM	TOTAL OFFSET
7119 IVP	Circle-fit 0.0000			0.0000
CAL PIER A			Brunson Nest with Prism 0.0526	0.0526
HAL1	Reported Ecc. 0.0083	Ant BCR Mech Offset 0.0345	Leica Nest with Prism (inverted) -0.0550	-0.0122
HAL2	Assumed Ecc. 0.0083	Ant TCR Mech Offset 0.1015	Leica Nest with Prism 0.0550	0.1648
KOLEKOLE	Range Pole B 1.0422	MTA C, Bottom Plate 0.0098	Leica Nest with Prism 0.0550	1.1070
MAO0	Reported Ecc. 0.0000	Ant BCR Mech Offset 0.0320	Leica Nest with Prism (inverted) -0.0550	-0.0230
MAUI	Reported Ecc. 0.0000	Ant BCR Mech Offset 0.0350	Leica Nest with Prism (inverted) -0.0550	-0.0200
T4 RM1	Chained Rod (taped) 1.221	MTA A, Bottom Plate 0.0098	Leica Nest with Prism 0.0550	1.2858
T4 RM2	Range Pole D 1.0426		Brunson Nest with Prism 0.0526	1.0952

T4 RM3	Range Pole C 1.0425		Brunson Nest with Prism 0.0526	1.0951
UH HIG5 [1]	Range Pole A 1.0426		Brunson Nest with Prism 0.0526	1.0952
UH HIG5 [2]	Range Pole E 1.0424		Brunson Nest with Prism 0.0526	1.0950

Table 3

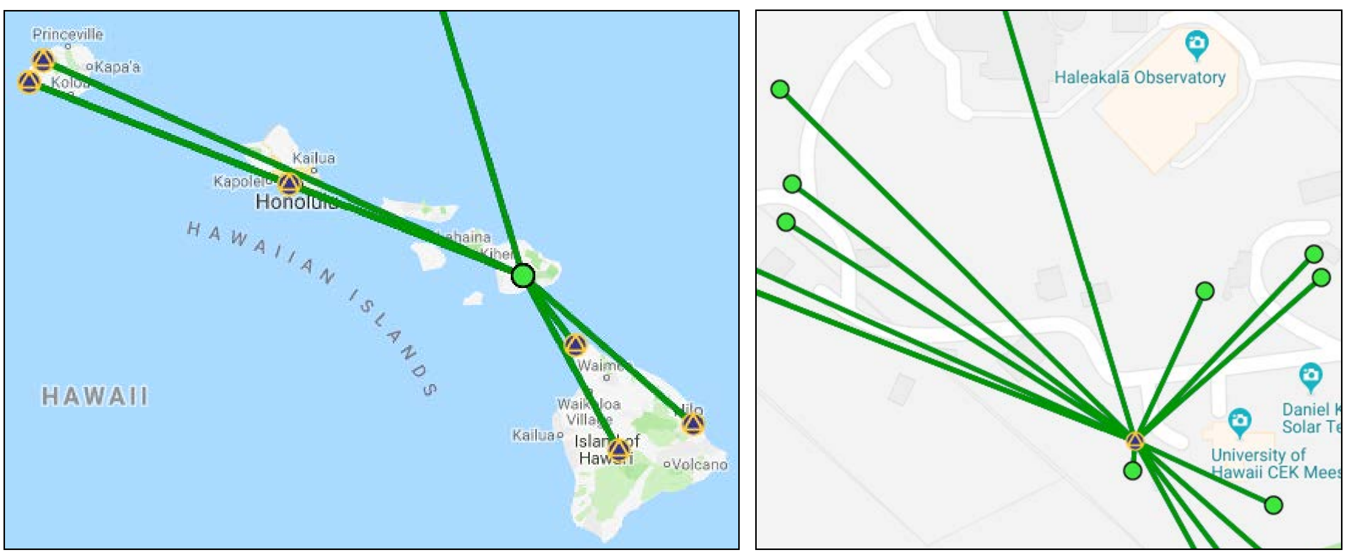
4.2 Leveling

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, 2019/03/11. 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 IGS tracking station MAUI. 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, reported eccentricities are from station site logs)

STATION	OFFSET 1	OFFSET 2	TOTAL OFFSET
CAL PIER A		MTA B, Overall 0.1507	0.1507
HAL1	Reported Ecc. 0.0083		0.0083

HAL2	Assumed Ecc. 0.0083		0.0083
KOLEKOLE	Range Pole B 1.0422	MTA C, Overall 0.1507	1.1929
MAO0	Reported Ecc. 0.0000		0.0000
MAUI	Reported Ecc. 0.0000		0.0000
T4 RM1	Chained Rod (taped) 1.221	MTA A, Overall 0.1507	1.3717
T4 RM3	Range Pole C 1.0425		1.0425
TP01	Range Pole E 1.0424	MTA B, Overall 0.1507	1.1931
TP03	Range Pole A 1.0426	MTA A, Overall 0.1507	1.1933

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 SLR instrument 7119 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.

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 invariant point (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.

Target/reflector affixed to SLR antenna for azimuth and elevation rotation sequences

Coordinates for the GNSS stations were also determined using the circle-fitting routine. Three-dimensional measurements were taken to a target/reflector at multiple points along antenna. A sufficient number of points were measured to scribe a circle in space. After accounting for reflector offsets, mechanical offsets, and mark eccentricities, coordinates were computed to represent the space geodetic technique reference points. 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 technique reference points.

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

Surveyed topocentric coordinates, ITRF2014 (epoch 2019/03/11)						
STATION	***E(m)***	***N(m)***	***U(m)***	***SE(m)***	***SN(m)***	***SU(m)***
Space geodetic technique stations						
MAUI	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7119 IVP	10.7580	-18.3282	-3.1985	0.0003	0.0002	0.0001
7119 MARK	10.7550	-18.3312	-5.8285	0.0003	0.0002	0.0001
HAL1	82.2605	84.0183	10.7618	0.0005	0.0006	0.0002
HAL2	-155.7772	115.5866	-16.5646	0.0005	0.0007	0.0007
MAO0	5.8969	-4.4695	-1.1563	0.0002	0.0003	0.0001
Ground network marks						
CAL PIER A	32.3773	67.408	5.0508	0.0004	0.0003	0.0002
KOLEKOLE	85.7593	73.7583	8.1834	0.0005	0.0006	0.0002
T4 RM1	63.9587	-29.0882	-3.1011	0.0003	0.0005	0.0001
T4 RM2	6.7665	-21.9828	-6.0372	0.0003	0.0003	0.0001
T4 RM3	-0.5451	-13.8275	-5.6075	0.0002	0.0002	0.0001
UH HIG5	18.5502	-5.2183	-3.2573	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 2019/03/11)						
STATION	***X(m)***	***Y(m)***	***Z(m)***	***SX(m)***	***SY(m)***	***SZ(m)***
Space geodetic technique stations						
MAUI	-5466069.0684	-2404327.1975	2242127.8966	0.0000	0.0000	0.0000
7119 IVP	-5466067.9302	-2404338.4496	2242109.6214	0.0002	0.0002	0.0002
7119 MARK	-5466065.6805	-2404337.4568	2242108.6887	0.0002	0.0003	0.0002
HAL1	-5466017.9690	-2404394.5875	2242210.2928	0.0003	0.0006	0.0005
HAL2	-5466080.1961	-2404161.9110	2242230.1597	0.0007	0.0005	0.0007
MAO0	-5466067.1506	-2404332.7961	2242123.3070	0.0002	0.0002	0.0003
Ground network marks						
CAL PIER A	-5466038.5398	-2404349.1401	2242192.7361	0.0002	0.0004	0.0003
KOLEKOLE	-5466017.6733	-2404398.2797	2242199.7839	0.0002	0.0005	0.0005
T4 RM1	-5466050.0757	-2404388.7160	2242099.5909	0.0003	0.0002	0.0005
T4 RM2	-5466068.2896	-2404334.2471	2242105.1992	0.0002	0.0002	0.0003
T4 RM3	-5466068.9619	-2404326.5552	2242112.9796	0.0001	0.0002	0.0002
UH HIG5	-5466060.4994	-2404343.6937	2242121.8637	0.0001	0.0002	0.0002

Table 6: Coordinate estimates for network stations

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

Surveyed topocentric ties				
STATION	***EAST (m)***	***NORTH (m)***	***UP (m)***	***DIST (m)***
MAUI	0.0000	0.0000	0.0000	0.0000
7119 IVP	10.7580	-18.3282	-3.1985	21.4916
7119 MARK	10.7550	-18.3312	-5.8285	22.0380
HAL1	82.2605	84.0183	10.7618	118.0749
HAL2	-155.7772	115.5866	-16.5646	194.6823
MAO0	5.8969	-4.4695	-1.1563	7.4891
Surveyed geocentric ties				
STATION	***X (m)***	***Y (m)***	***Z (m)***	***DIST (m)***
MAUI	0.0000	0.0000	0.0000	0.0000
7119 IVP	1.1382	-11.2521	-18.2752	21.4916
7119 MARK	3.3879	-10.2593	-19.2079	22.0380
HAL1	51.0994	-67.3900	82.3962	118.0750
HAL2	-11.1277	165.2865	102.2631	194.6823
MAO0	1.9178	-5.5986	-4.5896	7.4891

Table 7: Local tie vectors emanating from MAUI

5.3 Additional parameters

SLR Calibration Pier

CAL PIER A is represented by a threaded rod forced-centering device. For calibration of the SLR telescope, the pier is occupied by a prism. Station CAL PIER A represents the surveyed position of the pier with the prism removed. To aid SLR operations, the pier was also observed with the prism in place and assigned the name CAL PIER A PRISM. Ties from the SLR telescope invariant point (IVP) to the pier are provided below in each configuration.

From: 7119 IVP, aka HA4T, aka TLRS-4
To: CAL PIER A

Slope distance:	88.8039 m	
Geodetic azimuth:	14°09’09.85”	(14.1527°)
Elevation angle:	5°19’47.87”	(5.3300°)
Zenith angle:	84°40’12.13”	(84.6700°)

From: 7119 IVP, aka HA4T, aka TLRS-4
To: CAL PIER A PRISM

Slope distance:	88.8404 m	
Geodetic azimuth:	14°09’14.78”	(14.1541°)
Elevation angle:	5°22’17.54”	(5.3715°)
Zenith angle:	84°37’42.46”	(84.6285°)
Prism constant:	0.0312 m	

Reported values from 2013 previous survey

Calibration distance:	88.840 m
Geodetic azimuth:	14.1547°
Elevation angle:	+05.3699°
Prism constant:	+0.0319 m

<u>SLR telescope axial offsets</u>
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.

7119 offset: 1.4 mm +/- 0.7 mm

<u>Geoid model used</u>
Because the project site spanned about 300 meters, geoid model USGG2012 was applied to the observations to account for local geoid undulations. Geoid heights for stations at the site had a range of up to about 2 millimeters.

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 ***NGSMAUI1903GA.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              =      5

             Number of Stations      =     34

             Number of Observations  =    764
             Number of Unknowns      =    148
             Number of Redundant Obs =    616

Observation   Count   Sum Squares        Error
                        of StdRes        Factor
Coordinates       3       0.000          0.000
 Directions     193     156.214          1.002
  Distances     194     162.639          1.020
Az/Bearings       1       0.000          0.000
    Zeniths     192     152.589          0.993
 Elev Diffs       1       0.000          0.000
 GPS Deltas     180     131.140          0.951

      Total     764     602.582          0.989

      The Chi-Square Test at 5.00% Level Passed
           Lower/Upper Bounds (0.944/1.056)
```

Comparison with IERS computed tie

ITRF2014 (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, ITRF2014 (epoch 2019/03/11)				
STATION	***SOL***	***X (m)***	***Y (m)***	***Z (m)***
MAUI	-	-5466069.0684	-2404327.1974	2242127.8965
7119 MARK	-	-5466065.6788	-2404337.4533	2242108.6883

Table 8: IERS computed coordinates

Surveyed tie vs. IERS computed tie						
	NGS 2019 geocentric tie discrepancies			**NGS 2019 topocentric tie discrepancies**		
STATION	***DX(mm)***	***DY(mm)***	***DZ(mm)***	***DE(mm)***	***DN(mm)***	***DU(mm)***
MAUI	0.0	0.0	0.0	0.0	0.0	0.0
7119 MARK	-1.7	-3.4	0.4	2.4	-0.8	2.9

Table 9: Tie discrepancies between surveyed and computed ties (surveyed minus computed)

Comparing against the ITRF2014 computed coordinates, the current survey has a maximum tie discrepancy of 2.9 millimeters in the up component.

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 (Strategic Service 2013) Topocentric tie discrepancies			
STATION	***DE (mm)***	***DN (mm)***	***DU (mm)***
MAUI	0.0	0.0	0.0
7119 IVP	-0.2	-0.5	0.7
7119 MARK	-0.2	-0.3	1.1
CAL PIER A	-1.8	2.1	1.6
KOLEKOLE	-2.4	2.7	2.1
T4 RM1	6.9	2.0	-1.5
T4 RM3	-1.0	0.3	-0.9
UH HIG5	0.7	0.5	1.7

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

6 Planning aspects

Physical address of project site:

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Haleakala Hwy, Kula, HI 96790

On-site contact:

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Haleakala Observatory Site Supervisor
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Contact for GNSS stations and data:

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<u>Recommendations</u>

Coordinate the survey schedule with the on-site staff in advance to take advantage of non-observing periods. The project site is located within Haleakala National Park. Contact the site supervisor for a parking permit to avoid park fees. The survey team lodged in Kahului, Maui, a 75-minute drive from the site, as no closer options could be found.

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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7.3 Location of observation data and results archive

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

7.4 Works referenced

Carpenter, Troy (2013). NASA Haleakala TLRS4 Post-Maintenance Final Geodetic Survey Report.

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