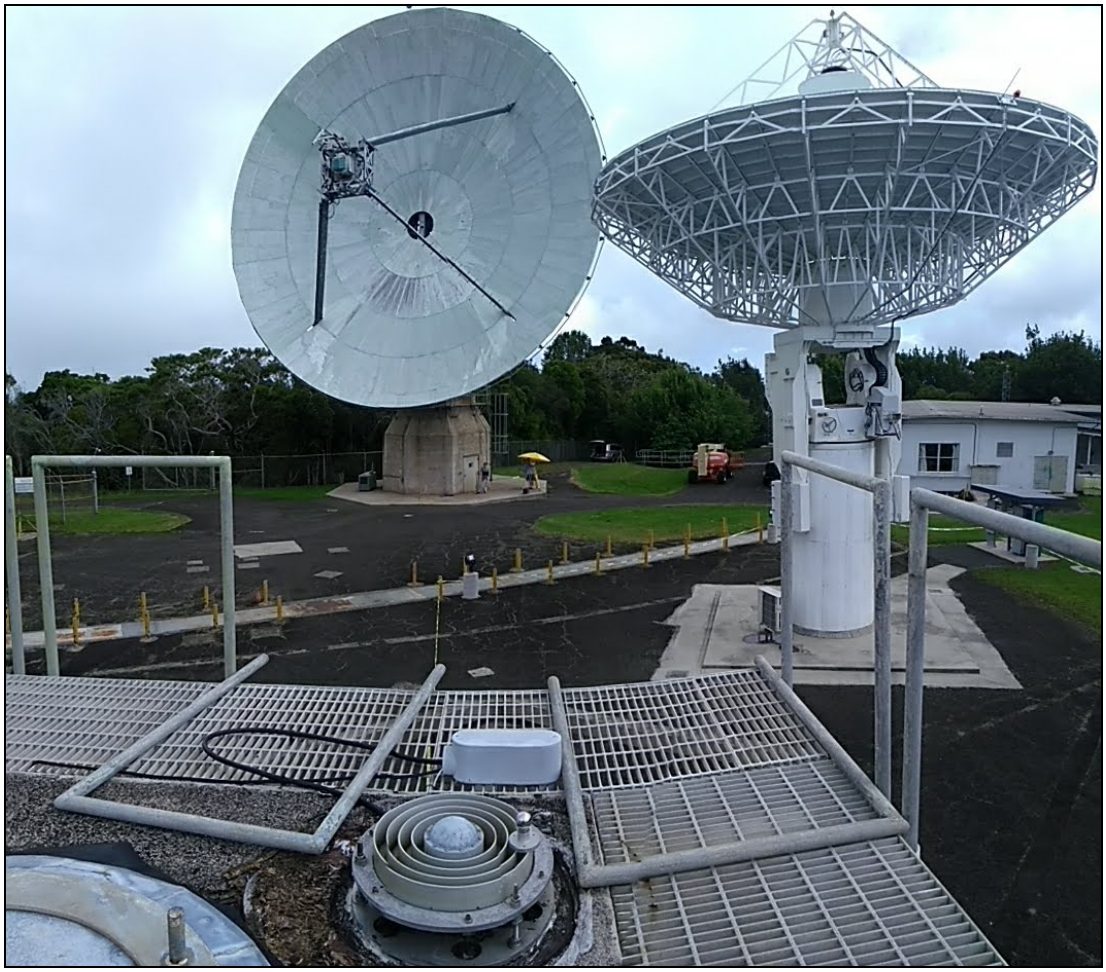
UNITED STATES DEPARTMENT OF COMMERCE
NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE
NATIONAL GEODETIC SURVEY

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



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Dates of Data Collection: June 2018
Date of Report: March 2019

Introduction

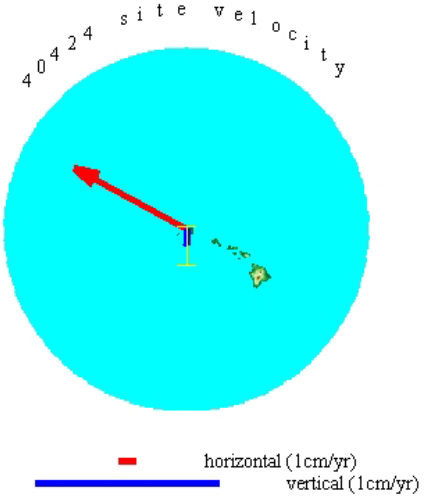
In June 2018, the National Geodetic Survey (NGS) conducted a local tie survey at NASA's Kokee Park Geophysical Observatory. The observatory is an International Earth Rotation and Reference Systems Service (IERS) site (designated Kauai) located on the Island of Kauai, Hawaii, USA. The site features co-located space geodetic technique (SGT) instruments that contribute to realizations of the International Terrestrial Reference Frame (ITRF).

Space geodetic techniques at the site include Very Long Baseline Interferometry (VLBI), Global Navigation Satellite Systems (GNSS), and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS). GNSS station KOKB 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, ITRF2014 (2018/06/10). This report documents the instrumentation, observations, analysis, and results of the survey.

1 Site description

IERS site name: Kauai
IERS site number: 40424
Country name: United States of America
Surveying institution: National Geodetic Survey
Dates of survey: June 7 - 13, 2018
Longitude: W 200° 19'
Latitude: N 22° 07'
Tectonic plate: Pacific



SGT Technique	Name	DOMES#	Description
GNSS	KOKB	40424M004	Forced centering device on the roof of a concrete tower. Also known as KOKV.
GNSS	KOKF	40424M008	Reference point of a SCIGN antenna mount on top of an 8.2-m steel tower
GNSS	KOKG	40424M009	Reference point of a SCIGN antenna mount on top of an 8.2-m steel tower
GNSS	KOKR	40424M010	Reference point of a SCIGN antenna mount on top of a 5-m steel mast
GNSS	KOKC	40424M011	Reference point of a self-centering antenna mount on top of a steel mast
VLBI	7298	40424S007	20-m VLBI antenna/AZ-EL

DORIS	KOLB	40424S009	DORIS Antenna ref. pt (Starec type)
VLBI	7623	40424S010	12-m VLBI antenna

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 8/20/2008). 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 9,0,3,6298) from MicroSurvey. Coordinate transformations, invariant point determinations, 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 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.

2.3.3 Checks carried out before measurements

Not applicable.

2.4 Tripods

Wooden surveying tripods with collapsible legs were used to support surveying instrumentation and target reflectors. Fixed-height range poles with attached tripod support legs were used with target reflectors and GNSS antennas.

Surveying tripod for instrumentation

Fixed-height range pole

2.5 Forced centering devices

Target reflectors and GNSS antennas 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.

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 were affixed to the mark forced centering devices using the 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. Several non-monumented temporary marks were also established to facilitate the survey. VLBI antennas 7298 and 7623 do not have associated physical reference points. The reference point for IGS station KOKB is a divot in the GNSS antenna mount that was inaccessible; likewise for the site's other GNSS stations. The VLBI and GNSS space geodetic techniques were observed indirectly. The reference point for DORIS station KOLB is a divot in a domed screw under the antenna, which was able to be occupied for observations.

Previous surveys of the site were conducted in 2014 by NGS and in 2002 by Allied Signal Technical Services (AST). The current survey included marks from the previous surveys 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				
KOKB	40424M004	KOKB	--	AI4962
KOKF	40424M008	KOKF	--	--
KOKG	40424M009	KOKG	--	--
KOKR	40424M010	KOKR	--	--
KOKC	40424M011	KOKC	--	--
7298	40424S007	7298	SGP 7298	--
KOLB	40424S009	KOLB	KOLB	--

7623	40424S010	--	--	--
Ground network marks				
1311 NCMN A	--	--	1311 NCMN A	--
1311 NCMN B	--	--	1311 NCMN B	--
1311 NCMN D	--	--	--	--
KOK9	--	--	--	--
KOKEE	--	--	KOKEE	TU0791
KOLB MARK	--	--	KOLB (ground mark)	--
NGS A	--	--	NGS A	--
NGS B	--	--	NGS B	--
PEACESAT	--	--	--	--

Table 2: Listing of SGT stations and ground network marks

Ground network mark descriptions

1311 NCMN A is a NASA survey disk, stamped 1311 NCMN A JUN 89, set in top of a round concrete monument.

1311 NCMN B is a NASA survey disk, stamped 1311 NCMN B JUN 89, set in top of a round concrete monument.

1311 NCMN D is a NASA survey disk, stamped 1311 NCMN D JUN 89, set in top of a round concrete monument.

KOK9 is US Coast & Geodetic Survey reference mark disk, stamped KOKEE NO 1 1961. It is also known as KOKEE RM 1. It is a NASA GNSS station, occupied by a choke ring antenna, Javad JAVRINGANT_DM, serial number 00591. Per the site log, the ARP is eccentric from the mark by 0 m East, 0 m North, and 1.184 m Up.

KOKEE is a US Coast & Geodetic Survey triangulation station disk, stamped KOKEE 1961, set in top of a round concrete post that is 30 cm in diameter.

KOLB MARK is a 20-mm brass disk set in the center of a concrete roof of a 7.4-meter tall, 2.4-meter square concrete tower. The mark hosts a DORIS antenna (Starec 52291 type, serial number 96).

NGS A is a masonry “PK” nail set in top of and near the northeast corner of the cement roof of a small, concrete block communications building.

NGS B is a masonry “PK” nail set in the top center of a concrete footer slab.

PEACESAT is a NASA survey disk, stamped PEACESAT 72, set near the top center of a concrete footer slab.

3.1.2 Map of network

Kokee Park Geophysical Observatory (KPGO)

Space geodetic techniques in the VLBI site area

Space geodetic techniques in the DORIS site area

3.2 Representation of technique reference points

3.2.1 VLBI

The site hosts two VLBI technique instruments. Each instrument is represented by a theoretical point in space: the invariant point about which the azimuth and elevation axes rotate.

7298 is a VLBI radio telescope with 20-meter dish antenna operated by NASA.

7623 is a VLBI radio telescope with 12-meter dish antenna operated by NASA. The instrument was installed at the observatory in the time since the previous survey of 2014. It has been assigned a DOMES number, per the International VLBI Service, but does not yet appear in published ITRF solutions.

VLBI SGTs 7623 (left) and 7298 (right)

3.2.2 SLR

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

3.2.3 GNSS

The site hosts five GNSS technique instruments that are maintained by NASA and 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.

KOKB is an IGS tracking station. Per the IGS station site log, it is represented by a forced-centering device in a “Dinardo-type steel plate.” The current GNSS antenna is an Ashtech choke ring, model number ASH701945G_M, serial number CR6200342010. Per the site log, the antenna reference point (ARP) is eccentric from the mark KOKB by 0.000 m East, 0.000 m North, and 0.0614 m Up.

Station KOKB is also known as KOKV, differentiated by separate GNSS receivers connected to a single GNSS antenna occupying a single physical point. For this survey, KOKB is the site marker.

KOKB


KOKF

KOKF is represented by the reference point of a SCIGN antenna mount on top of an 8.2-m steel tower. It is east of station KOKG. KOKF is occupied by a choke ring antenna, Javad JAVRINGANT_DM, serial number 00412. 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.

KOKG is represented by the reference point of a SCIGN antenna mount on top of an 8.2-m steel tower. It is west of station KOKF. KOKG is occupied by a choke ring antenna, Javad JAVRINGANT_DM, serial number 00801. 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.


KOKG


KOKR

KOKR is represented by the reference point of a SCIGN antenna mount on top of a 5-m steel mast. KOKG is occupied by a choke ring antenna, Trimble TRM59800.00, serial number 5129354198. Per the site log, the ARP is eccentric from the mark by 0 m East, 0 m North, and 0.0083 m Up.

KOKC is represented by the reference point of a forced-centering antenna mount on top of a 6-m steel mast. It is occupied by a choke ring antenna, Trimble TRM29659.00, serial number

0220366828. Per the site log, the ARP is eccentric from the mark by 0.0 m East, 0.0 m North, and 0.0800 m Up. While the mark was positioned, the station had been inactive for several years.

KOKC


KOLB

3.2.4 DORIS

KOLB 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 KOLB. The DORIS system is maintained by France's *Institut National de l'information Géographique et Forestière*.

4 Observations

4.1 Terrestrial survey

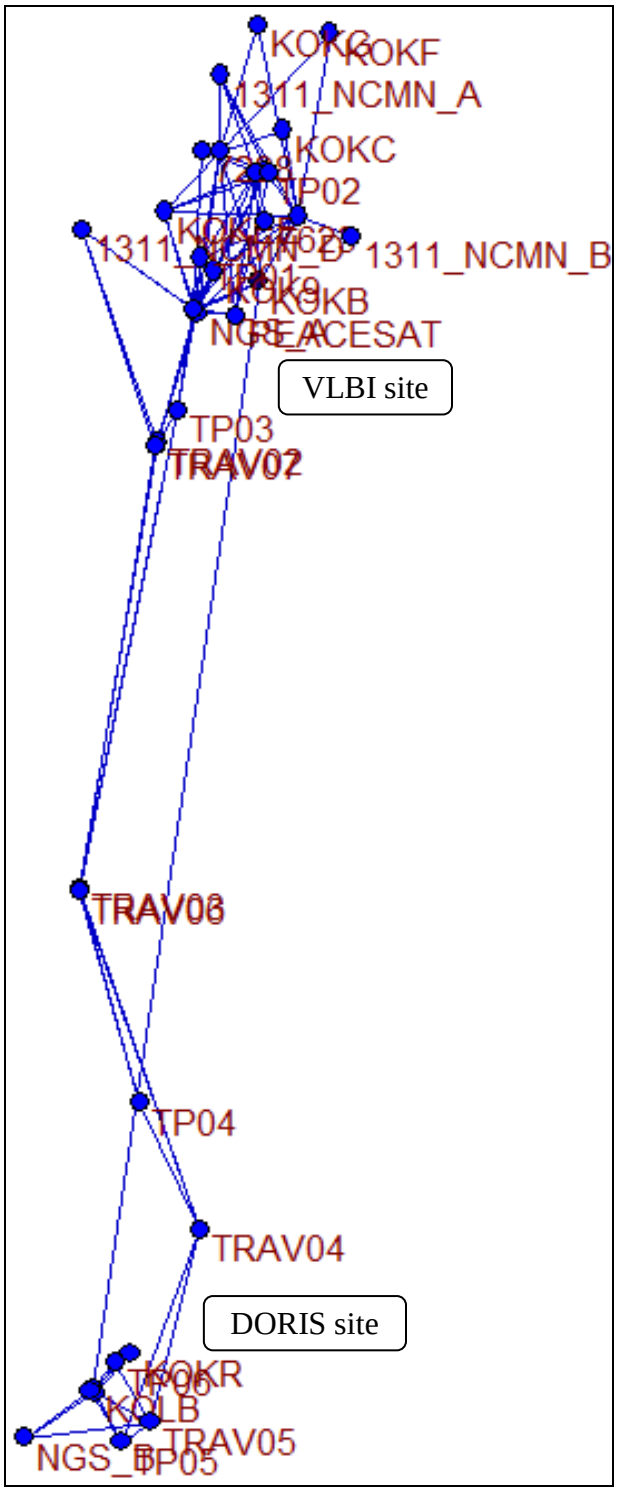
The terrestrial survey was completed using an absolute laser tracker system and a total station system. The instruments measured horizontal angles, vertical angles, and distances to retro-reflector targets which were used to position the marks and techniques.

The site features two distinct areas of space geodetic technique instruments separated by over 300 meters. To establish precise ties between the sites, a closed traverse, running forward and backward, was surveyed using the total station instrument. GNSS observations were also collected to support the terrestrial survey.

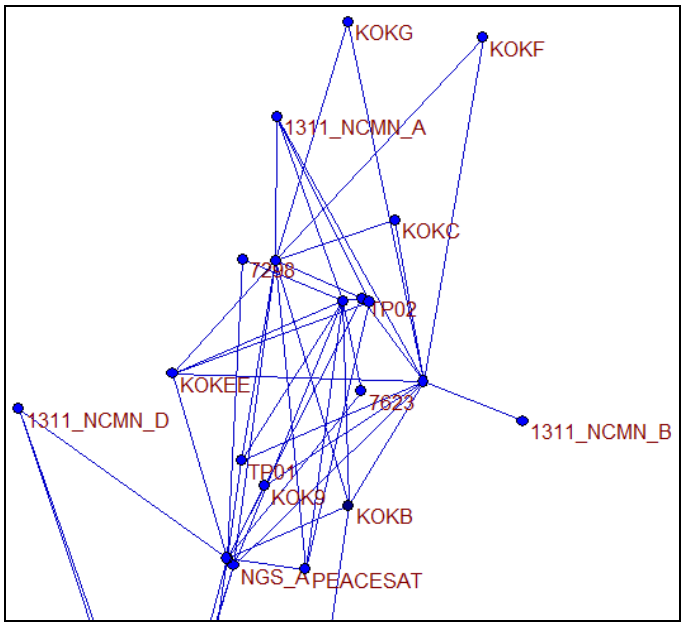
As part of the observation routine, all angle and distance measurements to ground marks were observed a minimum of three times. Double centering of the instrument was incorporated, measuring in both instrument faces. Meteorological data was observed and atmospheric corrections were applied to all measurements 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. GeoObs software was used for recording observations for all

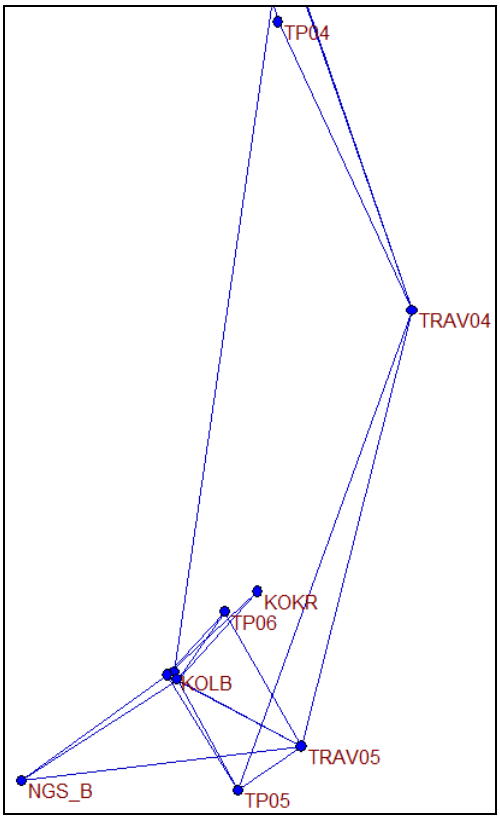
total station measurements. Star*Net software was used to combine and adjust all observations. A complete list of adjusted observations is available in Star*Net output file ***KokeePark.lst***.



Network stations at Kokee Park Geophysical Observatory



Network stations in the VLBI site area



Network stations in the DORIS site area

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

STATION	OFFSET 1	OFFSET 2	PRISM	TOTAL OFFSET
1311 NCMN A	Range Pole E 1.04242		Brunson Nest with Prism 0.05258	1.09500
1311 NCMN B	Range Pole C 1.04248		Brunson Nest with Prism 0.05258	1.09506
1311 NCMN D	Range Pole B 1.04224		Brunson Nest with Prism 0.05258	1.09482
KOK9	Reported ecc. 1.184	Ant TCR mech offset 0.1015	Leica Nest with Prism 0.05498	1.3405
KOKB [1]	Reported ecc. 0.0614	Ant TCR mech offset 0.1006	Leica Nest with Prism 0.05498	0.2170
KOKB [2]	Reported ecc. 0.0614	Ant TCR mech offset 0.1006	Silver Spacer w. Leica Nest/Prism 0.14648	0.3085
KOKC	Reported ecc. 0.0800	Ant TCR mech offset 0.1006	Leica Nest with Prism 0.05498	0.2356
KOKEE [1]	Trivet Rod 0.0936	Brunson Nest Recession -0.0015	Brunson Nest with Prism 0.05258	0.14468
KOKEE [2]	Range Pole D 1.04261		Brunson Nest with Prism 0.05258	1.09519
KOKF	Reported ecc. 0.0083	Ant TCR mech offset 0.1015	Leica Nest with Prism 0.05498	0.1648
KOKG	Reported ecc. 0.0083	Ant TCR mech offset 0.1015	Leica Nest with Prism 0.05498	0.1648
KOKR	Reported ecc. 0.0083	Ant TCR mech offset 0.1020	Leica Nest with Prism 0.05498	0.1653
KOLB [ARP]	Ant offset 0.390			0.3900
KOLB BASE			Leica Disk with Prism 0.0250	0.0250
KOLB MARK	Trivet Rod 0.0936	Brunson Nest Recession -0.0015	Brunson Nest with Prism 0.05258	0.14468
KOLB PHASE	Ant offset 0.877			0.8770
NGS A	Range Pole A 1.04260		Brunson Nest with Prism 0.05258	1.09518
NGS B	Range Pole C 1.04248		Brunson Nest with Prism 0.05258	1.09506
PEACESAT [1]	Trivet Rod 0.0936	Brunson Nest Recession -0.0015	Brunson Nest with Prism 0.05258	0.14468
PEACESAT [2]	Range Pole B 1.04224		Brunson Nest with Prism 0.05258	1.09482

4.2 Leveling

No leveling was conducted for this survey.

4.3 GNSS

GNSS data was collected to generate 3-dimensional IGS2014 vectors between stations at the epoch date of survey, 2018/06/10. Over multiple days, simultaneous long-session (24+ hour) observations were taken at stations KOK9, KOKB, KOKF, KOKG, KOKR, NGS A, NGS B and PEACESAT. 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 KOKB. Using the baseline processing engine within NGS's OPUS Projects software, IGS2014 vectors to the network stations and CORS were generated via IGS2014 satellite orbits. For the purpose of this survey, IGS2014 is aligned to ITRF2014 and the two are interchangeable. 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	TOTAL OFFSET
KOK9 [KOKEE RM1]	Reported ecc. 1.184
KOKB	Reported ecc. 0.0614
KOKF	Reported ecc. 0.0083
KOKG	Reported ecc. 0.0083

KOKR	Reported ecc. 0.0083
NGS A	Range Pole A 1.0426
NGS B	Range Pole C 1.04248
PEACESAT	Range Pole B 1.04248

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 sub-millimeter accuracies.

Establishing points via circle-fitting

Coordinates of the VLBI technique instruments 7298 and 7623 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 an established 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 must be 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 GRP.

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

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

Coordinates for the GNSS stations and DORIS station were also determined using the circle-fitting routine. Three-dimensional measurements were taken to a target/reflector at multiple points along the top of the antenna's choke ring or around the DORIS antenna. A sufficient number of points were measured to scribe a circle in space. After accounting for reflector offsets, mechanical offsets, and reported 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 preliminary analysis of the VLBI technique's azimuth axis and elevation axis. Circle-fitting was also used to determine the GNSS and DORIS techniques' reference points.

Terrestrial observations of the ground network and SGTs were brought from Spatial Analyzer and GeoObs 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 output file ***KokeePark.lst***. AXIS software was used for final analysis and computation of the radio telescopes' azimuth axes, elevation axes, axial offsets, and technique reference points.

5.1.2 Topocentric coordinates and covariance

AXIS was used to compile topocentric coordinate estimates from the combined geodetic adjustment. Using the GNSS observations, the terrestrial survey was aligned to the reference frame ITRF2014 (epoch 2018/06/10). Complete covariance information for all network station is available in AXIS output file ***output.axs***.

Surveyed topocentric coordinates, ITRF2014 (epoch 2018/06/10)						
STATION	***E(m)***	***N(m)***	***U(m)***	***SE(m)***	***SN(m)***	***SU(m)***
Space geodetic technique stations						
KOKB	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7298	-18.0207	41.8432	9.2264	0.0002	0.0002	0.0006
7623	2.1061	19.4968	1.2023	0.0002	0.0002	0.0003
KOKC	7.8192	48.5351	-1.2076	0.0002	0.0002	0.0001
KOKF	22.6639	79.5910	1.2887	0.0003	0.0002	0.0001
KOKG	-0.1940	82.2741	1.5377	0.0003	0.0002	0.0001
KOKR	-40.3051	-343.6072	-3.7380	0.0006	0.0002	0.0004
KOLB	-52.1969	-354.9800	-0.4004	0.0006	0.0002	0.0004
Ground network marks						
1311 NCMN A	-12.2302	66.1170	-6.8080	0.0003	0.0001	0.0000
1311 NCMN B	29.4955	14.4533	-4.8477	0.0002	0.0002	0.0001
1311 NCMN D	-55.9549	16.4205	-7.4741	0.0001	0.0002	0.0001
KOK9	-14.2919	3.3247	-5.9071	0.0002	0.0002	0.0001
KOKEE	-29.9234	22.4840	-5.5761	0.0001	0.0001	0.0000
KOLB BASE	-52.1970	-354.9790	-0.7904	0.0006	0.0002	0.0004
KOLB MARK	-52.1958	-354.9789	-1.3110	0.0006	0.0002	0.0004
KOLB PHASE	-52.1964	-354.9791	0.0866	0.0006	0.0002	0.0004
NGS A	-19.5133	-10.1578	-2.6482	0.0001	0.0001	0.0000
NGS B	-73.8475	-370.3514	-9.3124	0.0006	0.0002	0.0004
PEACESAT	-7.3597	-10.8244	-5.9945	0.0001	0.0001	0.0000

Table 5

5.1.3 Correlation matrix

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

5.1.4 Reference temperature of radio telescope

The International VLBI Service reports a reference temperature of VLBI SGT 7298 of 16.9 degrees Celsius. The reference temperature of radio telescope VLBI SGT 7623 is unknown. At the time of writing, file ***antenna-info.txt*** is available online.
https://ivscc.gsfc.nasa.gov/program/control_files.html

For this survey, no temperature corrections were applied.

5.2 GNSS

5.2.1 Analysis software

NGS's OPUS Projects software was used to process and analyze IGS2014 vectors (considered interchangeable with ITRF2014 vectors) between stations at the epoch date of survey (2018/06/10). The resulting vectors can be found in OPUS Projects output file ***network-final.gfile***.

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 output file ***KokeeParklst***. Further analysis of the VLBI GRPs was conducted in AXIS software.

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 2018/06/10). Complete covariance information for all network station is available in AXIS output file ***output.axs***.

Surveyed geocentric coordinates, ITRF2014 (epoch 2018/06/10)						
STATION	***X(m)***	***Y(m)***	***Z(m)***	***SX(m)***	***SY(m)***	***SZ(m)***
Space geodetic technique stations						
KOKB	-5543838.3169	-2054585.9076	2387810.3902	0.0000	0.0000	0.0000
7298	-5543837.8156	-2054566.5034	2387852.6270	0.0008	0.0004	0.0004
7623	-5543831.7436	-2054585.7175	2387828.9040	0.0005	0.0003	0.0003
KOKC	-5543817.4093	-2054586.4980	2387854.8962	0.0002	0.0004	0.0002
KOKF	-5543803.4508	-2054597.1563	2387884.6052	0.0002	0.0005	0.0004
KOKG	-5543810.6629	-2054575.4519	2387887.1845	0.0003	0.0005	0.0004
KOKR	-5543970.4298	-2054591.8855	2387490.6797	0.0006	0.0009	0.0003
KOLB	-5543981.4781	-2054583.2979	2387481.4015	0.0006	0.0010	0.0004
Ground network marks						
1311 NCMN A	-5543813.3026	-2054563.5941	2387869.0739	0.0002	0.0004	0.0002
1311 NCMN B	-5543818.7515	-2054610.1125	2387821.9533	0.0002	0.0003	0.0003
1311 NCMN D	-5543845.4703	-2054528.8847	2387822.7863	0.0002	0.0002	0.0003
KOK9	-5543836.9782	-2054570.1697	2387811.2451	0.0002	0.0002	0.0003
KOKEE	-5543835.9312	-2054553.1112	2387829.1182	0.0001	0.0002	0.0002
KOLB BASE	-5543981.1390	-2054583.1721	2387481.2556	0.0006	0.0010	0.0004
KOLB MARK	-5543980.6863	-2054583.0057	2387481.0596	0.0006	0.0010	0.0004
KOLB PHASE	-5543981.9006	-2054583.4550	2387481.5858	0.0006	0.0010	0.0004
NGS A	-5543846.3851	-2054568.0875	2387799.9830	0.0001	0.0002	0.0002
NGS B	-5543986.6895	-2054562.1397	2387463.8054	0.0006	0.0010	0.0004
PEACESAT	-5543839.4904	-2054578.4936	2387798.1051	0.0001	0.0002	0.0001

Table 6: Coordinate estimates for network stations, ITRF2014 (epoch 2018/06/10)

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

Surveyed topocentric tie				
STATION	***EAST (m)***	***NORTH (m)***	***UP (m)***	***DIST (m)***
KOKB	0.0000	0.0000	0.0000	0.0000
7298	-18.0207	41.8432	9.2264	46.4836
7623	2.1061	19.4968	1.2023	19.6470
KOKC	7.8192	48.5351	-1.2076	49.1757
KOKF	22.6639	79.5910	1.2887	82.7650
KOKG	-0.1940	82.2741	1.5377	82.2887

KOKR	-40.3051	-343.6072	-3.7380	345.9832
KOLB	-52.1969	-354.9800	-0.4004	358.7973
Surveyed geocentric tie				
STATION	***X (m)***	***Y (m)***	***Z (m)***	***DIST (m)***
KOKB	0.0000	0.0000	0.0000	0.0000
7298	0.5013	19.4042	42.2368	46.4836
7623	6.5733	0.1901	18.5138	19.6470
KOKC	20.9076	-0.5904	44.5060	49.1758
KOKF	34.8661	-11.2487	74.2150	82.7650
KOKG	27.6540	10.4557	76.7943	82.2887
KOKR	-132.1129	-5.9779	-319.7105	345.9832
KOLB	-143.1612	2.6097	-328.9887	358.7973

Table 7: Local tie vectors emanating from KOKB, ITRF2014 (epoch 2018/08/16)

5.3 Additional parameters

VLBI radio telescope axial offsets

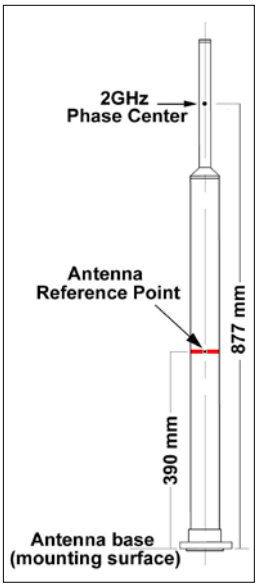
AXIS software was used to compute the offset distance between each radio telescope's azimuth and elevation axes.

SGT 7298 offset: 0.5163 m +/- 0.0003 m

SGT 7623 offset: 0.0022 m +/- 0.0003 m

For SGT 7298, the International VLBI Service reports an axial offset of 0.5180 m. At the time of writing, file ***antenna-info.txt*** is available online. https://ivscc.gsfc.nasa.gov/program/control_files.html. A previous survey by NGS in 2014 determined an axial offset of 0.5189.

No reported axial offset was found for SGT 7623.



Geometric properties of DORIS station

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

Surveyed ties from KOLB MARK			
STATION	***DE (m)***	***DN (m)***	***DU (m)***
KOLB MARK	0.0000	0.0000	0.0000
KOLB BASE	-0.0012	-0.0001	0.5206
KOLB ARP	-0.0011	-0.0011	0.9106
KOLB PHASE CTR	-0.0006	-0.0002	1.3976

Table 8

Geoid model usage and analysis

The size and location of the project site raised the possibility that the geoid was not uniform in the area. Geoid model USGG2012 was applied to the observations to account for local geoid undulations. As a check on the validity of the geoid model in this area, station height differences derived from GNSS and terrestrial observations were compared. Analysis suggested that the geoid heights at the site ranged up to about 4 centimeters, with a geoid model precision of up to about 2 millimeters.

Geoid model applied: USGG2012			
Height differences from KOKB			
STATION	*Ellip Ht (m)*	*Topocentric Ht (m)*	*Difference (mm)*
KOKB	0.0000	0.0000	0.0
KOK9	-5.8950	-5.9058	10.8
KOKF	1.2995	1.2938	5.7
KOKG	1.5479	1.5448	3.1
KOKR	-3.7145	-3.7487	34.2
NGS A	-2.6459	-2.6476	1.7
NGS B	-9.2916	-9.3208	29.2
PEACESAT	-5.9864	-5.9948	8.4

Table 9

Geoid model applied: None				
Height differences from KOKB				
STATION	*GNSS Survey Ellip Ht (m)*	*Terrestrial Survey Topocentric Ht (m)*	*Difference (mm)*	*Discrepancy (mm)*
KOKB	0.0000	0.0000	0.0	0.0
KOK9	-5.8950	-5.9058	10.8	0.0
KOKF	1.2995	1.2935	6.0	0.3
KOKG	1.5479	1.5445	3.4	0.3
KOKR	-3.7145	-3.7508	36.3	2.1
NGS A	-2.6459	-2.6476	1.7	0.0
NGS B	-9.2916	-9.3228	31.2	2.0
PEACESAT	-5.9864	-5.9949	8.5	0.1

Table 10

5.4 Transformations

IGS2014 GNSS vectors (considered interchangeable with ITRF2014 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 ***NGSKAUA1806GA.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 output file ***KokeePark.lst***.

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

                Iterations              =      5

                Number of Stations      =    172

                Number of Observations  =   1536
                Number of Unknowns      =    597
                Number of Redundant Obs =    939

     Observation   Count   Sum Squares         Error
                           of StdRes         Factor
     Coordinates       3        0.000         0.000
      Directions     472      282.924         0.990
       Distances     476      266.510         0.957
          Zeniths    472      289.164         1.001
      Elev Diffs       2        0.000         0.000
      GPS Deltas     111       68.907         1.008

           Total    1536      907.506         0.983

           The Chi-Square Test at 5.00% Level Passed
                Lower/Upper Bounds (0.955/1.045)
```

Comparison with IERS computed tie

ITRF2014 (epoch 2018/06/10) 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 2018/06/10)				
STATION	***SOL***	***X (m)***	***Y (m)***	***Z (m)***
KOKB	4	-5543838.3169	-2054585.9076	2387810.3901
7298	-	-5543837.8218	-2054566.5096	2387852.6322
KOLB	-	-5543981.4781	-2054583.3037	2387481.4029

Table 11: IERS computed coordinates

Surveyed ties vs. IERS computed tie									
	NGS 2018 geocentric tie discrepancies			NGS 2018 topocentric tie discrepancies			NGS 2014 topocentric tie discrepancies		
STATION	DX(mm)	DY(mm)	DZ(mm)	DE(mm)	DN(mm)	DU(mm)	DE(mm)	DN(mm)	DU(mm)
KOKB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7298	6.2	6.2	-5.3	-3.7	-1.9	-9.4	-1.2	-1.0	-13.2
KOLB	0.0	5.8	-1.5	-5.4	-1.0	-2.5	-4.0	5.2	-5.2

Table 12: 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 -9.4 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 NGS 2014 previous survey in ITRF2008 (epoch 2014/03/22). 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 2014) Topocentric tie discrepancies			
STATION	DE (mm)	DN (mm)	DU (mm)
KOKB	0.0	0.0	0.0
7298	-0.9	0.5	1.0
1311 NCMN A	-1.1	-0.3	-1.8
1311 NCMN B	4.0	-1.7	-1.2
KOKEE	-1.1	0.1	-1.5
KOLB	0.1	-0.8	-2.0
KOLB MARK	-0.1	-0.1	0.5
NGS A	-1.0	-0.7	-0.3
NGS B	-0.5	-2.4	-0.5

Table 13: Tie discrepancies between current survey and previous survey (current minus previous)

6 Planning aspects

Physical address of project site:

Kokee Park Geophysical Observatory (KPGO)
Kokee Rd, Waimea, Kauai, Hawaii 96796

Contact for information on previous site surveys and KPGO geodetic technique instruments:

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FMD Engineering Branch, Code 224
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Contact for GNSS stations and data:

David Stowers
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On-site contact:

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KPGO Station Manager - NASA/SCNS
Peraton (NASA contractor)
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Contact for DORIS station:

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Recommendations

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.

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

7 References

7.1 Name of person(s) responsible for observations

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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

Fancher, Kendall et al (2015). Local Tie Information Report, IERS Network Site: Kauai, HI. National Geodetic Survey. URL https://www.ngs.noaa.gov/corbin/iss/

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 VLBI Service. https://ivscc.gsfc.nasa.gov/

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