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

Kevin Jordan
Steven Breidenbach
Kendall Fancher

Date of Survey:

Date of Survey: May 2023
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Contents

Introduction

In May 2023, 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, IRTF2020 (2023/05/13). This report documents the instrumentation, observations, analysis, and results of the survey

1 ITRF SITE INFORMATION

IERS site name:	Kauai
IERS site number:	40424
Country name:	United States of America
Surveying institution:	National Geodetic Survey
Dates of survey:	May, 2023
Longitude:	W 200° 19'
Latitude:	N 22° 07'
Tectonic plate:	Pacific

DOMES 40424	Name	SGT Instrument	Description
S007	7298	VLBI	20-m VLBI antenna/AZ-EL
S010	7623	VLBI	12-m VLBI antenna
M004	KOKB	GNSS	Forced centering device on the roof of a concrete tower. Also known as KOKV.
S009	KOLB	DORIS	DORIS Antenna ref. pt (Starec type)

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

2 Instrumentation

2.1 Tacheometers, EDMI, theodolites

2.1.1 Description

Leica TS60, S/N 886928 (Total Station)
Specifications:
Angular measurement uncertainty of instrument: +/- 0.5”
Combined uncertainty of distance measurement throughout instrument range: +/- 0.6 mm

2.1.2 Calibrations

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

2.1.3 Auxiliary equipment

Omniport 30 meteo-station, S/N 01904161308007
Accuracy: Air temperature: +/- 0.20 C
Pressure: +/- .5 mbar
Relative Humidity: +/- 2%

2.1.4 Analysis software

Terrestrial observations and analysis were conducted with commercially available software Spatial Analyzer (version 2022.3.1123.3) from New River Kinematics. Least squares adjustments were conducted with commercially available software Star*Net (version 11,0,6,2263) from MicroSurvey. Coordinate transformations and SINEX generation were conducted with AXIS software from Geoscience Australia.

2.2 GNSS units

2.2.1 Receivers

Trimble NetR9, P/N: 67668-30, S/Ns: 5834R50367, 5832R50341, 5834R50359
Specifications for Static GPS Surveying: Horizontal: +/- 5 mm + 0.5 ppm RMS Vertical: +/- 5 mm + 1 ppm RMS

2.2.2 Antennas

Trimble GPS ground plane antenna, Zephyr Geodetic Model 3, P/N 115000-00, S/Ns: 6122223767, 6122223804, 6122223879

2.2.3 Analysis software

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

2.3 Leveling

No leveling instrumentation was used in this survey.

2.3.1 Leveling instruments

Not applicable.

2.3.2 Leveling rods

Not applicable.

2.4 Tripods

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

Surveying tripod for instrumentation

Fixed-height range pole

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 occupied the marks using the forced-centering devices and adapters above.

2.7 Additional instrumentation

No additional instrumentation was used in this survey.

3 Measurement setups

3.1 Ground network

The site has a network of existing ground marks which were recovered. A temporary control mark, TP01 was 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 were conducted in 2015 and 2018 by NGS and 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	KOKB	AI4962
KOKF	40424M008	KOKF	KOKF	--
KOKG	40424M009	KOKG	KOKG	--
KOLB	40424S009	KOLB	KOLB	--
7298	40424S007	7298	7298	--
7623	40424S010	7623	7623	--
Ground network marks				
1311 NCMN A	--	--	1311 NCMN A	--
KOKEE	--	--	KOKEE	TU0791
NGS A	--	--	NGS A	--
NGS B	--	--	NGS B	--
PEACESAT	--	--	PEACESAT	--
KOLB MARK	--	--	KOLB MARK	--
TP01	--	-	--	--

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 A

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.

KOKEE

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 A

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

NGS B

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).

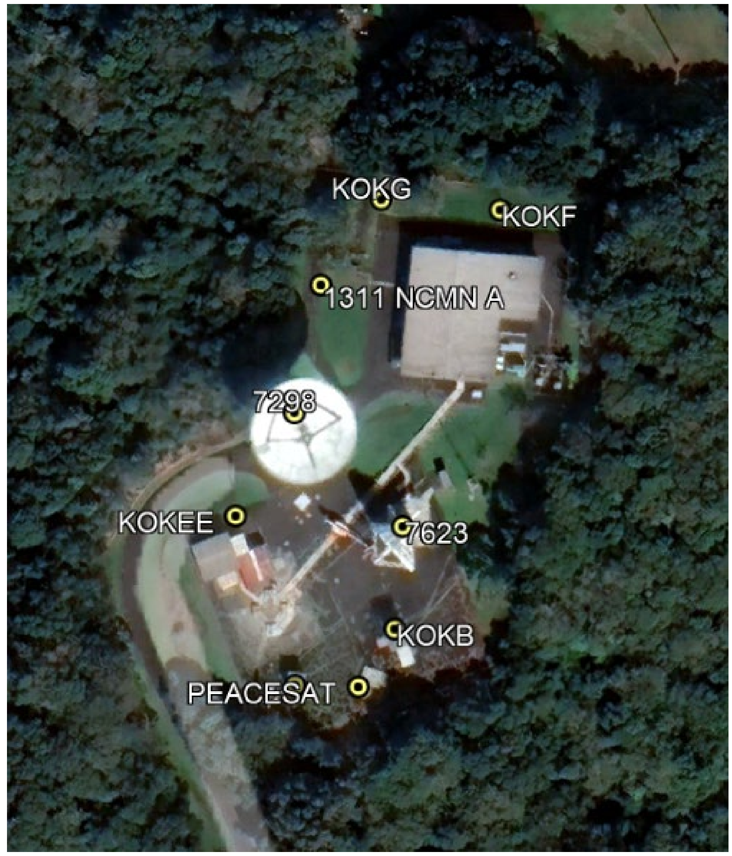
KOLB MARK

TP01 is a punch mark on the southeast bolt on the southernmost pad of three pads approximately 165 meters South of the DORIS.

TP01

3.1.2 Map of network

Kokee Park Geophysical Observatory



Space geodetic techniques and ground marks in the VLBI area

Space geodetic techniques and ground marks 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.

VLBI SGTs 7298 (left) and 7623 (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.   For this survey, only three GNSS antennas were observed: KOKB, KOKF and KOKG. 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 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.

KOKF

KOKG

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*.

KOLB DORIS

4 Observations

4.1 Terrestrial survey

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

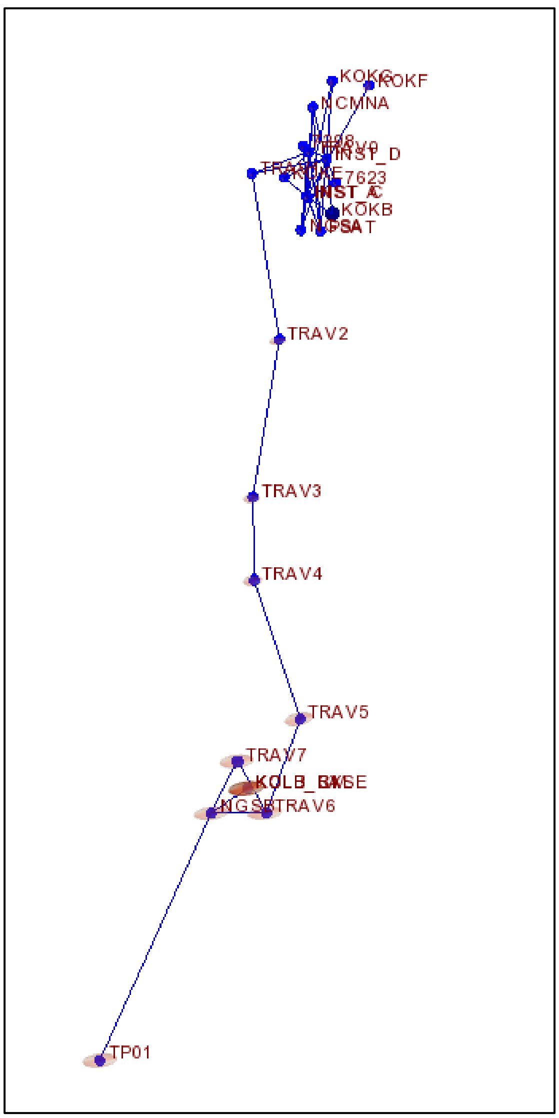
Lastly, NGS has developed tools to automate astronomical measurements of deflections of the vertical (DoV) and astronomic azimuths. The *Total Station Astrogeodetic Control System* (TSACS) is a hardware and software kit that directs a robotic total station to gather imagery of a selected set of stars. NGS has deployed this system in Alaska to verify geoid undulations and orthometric heights and tested it at dozens of locations throughout the United States. In 2022, NGS explored the use of illuminated imaging targets and automated routines for determination of astronomic azimuths.

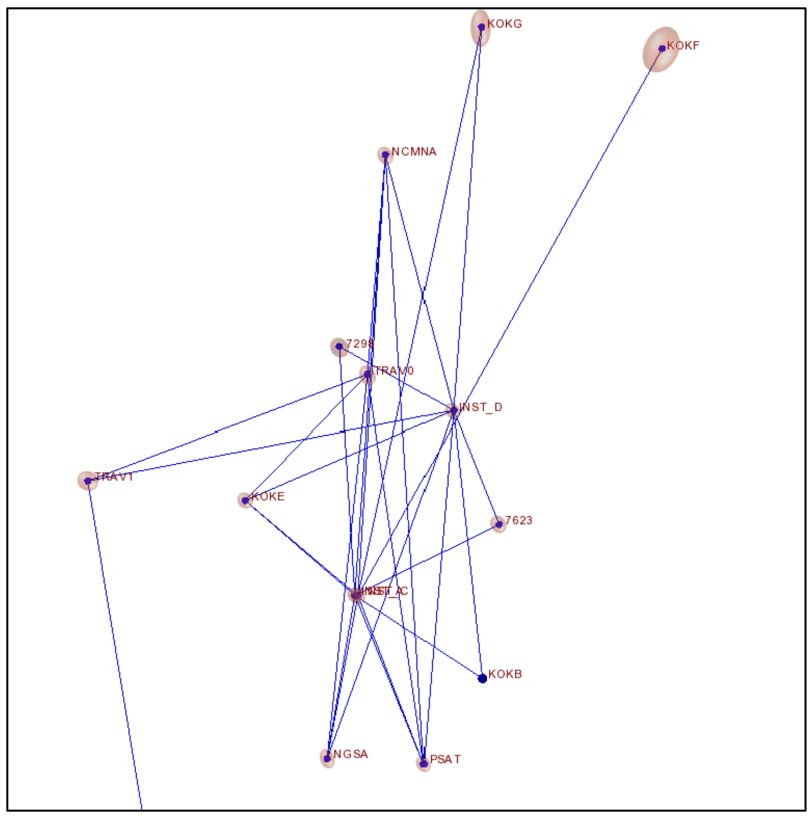
During the scheduled survey at the KPGO, NGS implemented both TSACS DoV and astronomic azimuth capabilities. NGS gathered a set of 4 DoV measurements on PEACESAT, NGS B and TP01, with each measurement session imaging 25 bright stars over the course of 15 minutes. These images were used to measure their zenith angles and ultimately estimate the deflection of the vertical at that location. A set of 12 astronomic azimuths were gathered and used in the survey, in which the total station repeatedly alternated between imaging Polaris and an illuminated terrestrial imaging target mounted on points in the survey network. Four of these observations were performed with the instrument on PSAT, with NCMNA as a target. Four observations were performed with the instrument on TP01, with NGSB as a target. A pair of reciprocal observations from TRAV2 to TRAV3 was also performed to check the internal consistency of the measurement.

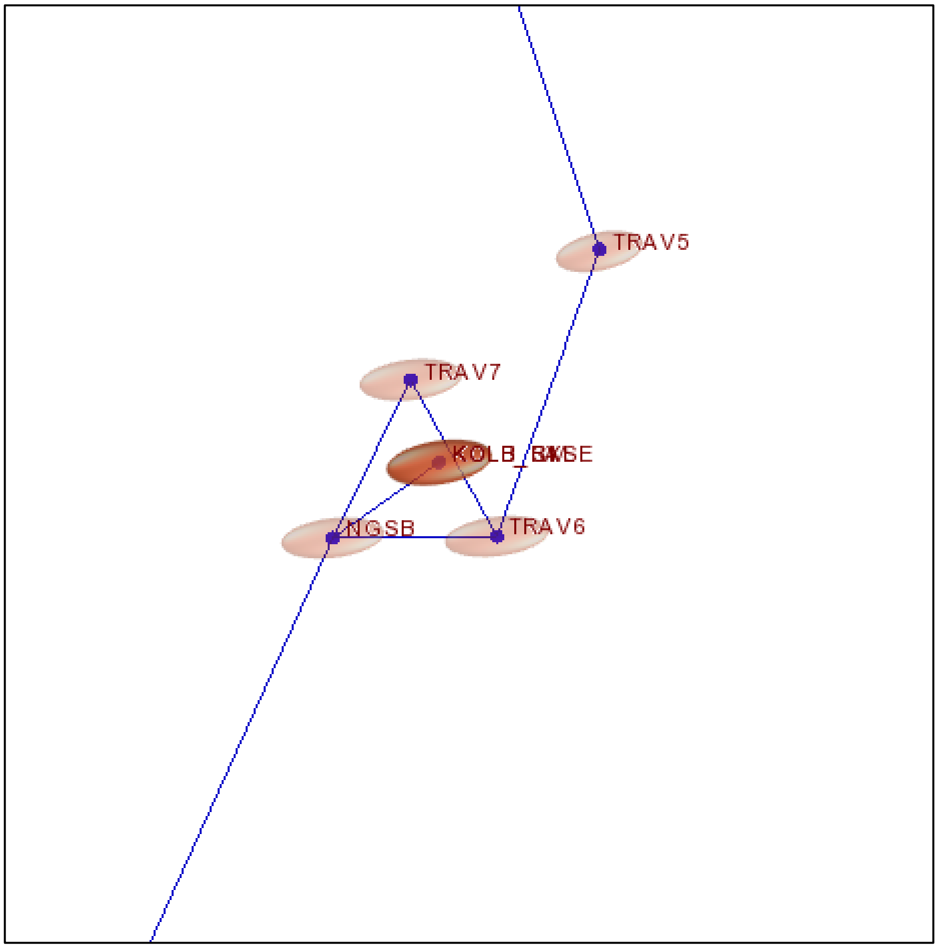
As part of the observation routine, all angle and distance measurements to ground marks were observed a minimum of three times. Double centering of the instrument was incorporated, measuring in both instrument faces. Meteorological data was observed and atmospheric corrections were applied to all measurements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

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

DoV Observation using TSACS







Network Stations at KPGO

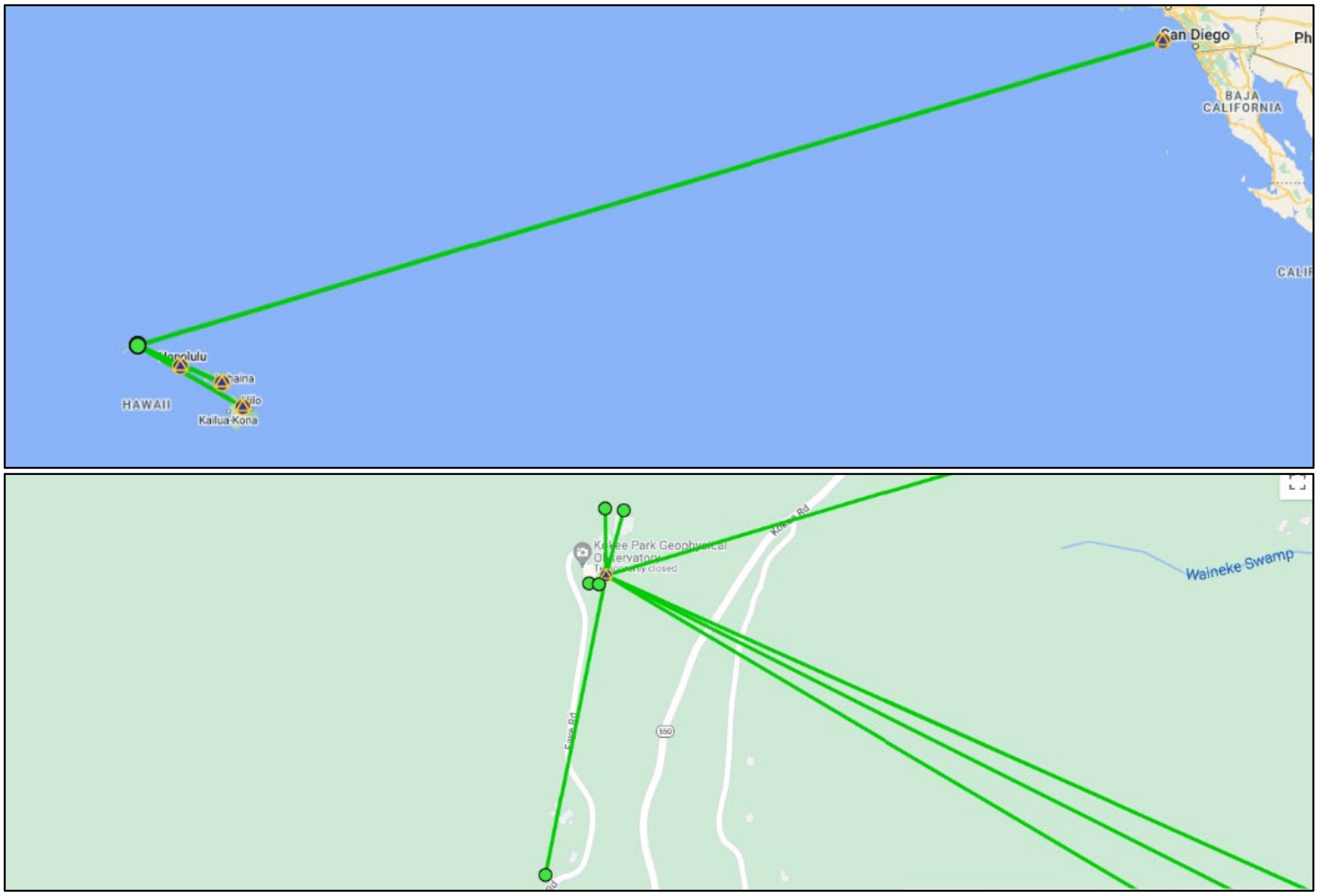
4.2 Leveling

No leveling was conducted for this survey.

4.3 GNSS

GNSS data was collected to generate 3-dimensional ITRF2020 vectors between stations at the epoch date of survey, 2023/05/13. Over multiple days, simultaneous long-session (24+ hour) observations were taken at several ground marks. Publicly available observation data was also obtained for CORS in the region.

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



GNSS Network Diagram

4.4 General comments

Resection method for terrestrial observations

In the terrestrial survey, the resection principle was employed to measure between ground marks indirectly with the total station. The ground marks were occupied with the reflector targets mounted on range poles. The instrument did occupy NGSB directly, but the remainder were setup at an arbitrary point between the marks. At each instrument occupation, a series of measurements were taken to the surrounding visible reflector targets. By observing common targets from different instrument occupations, the relative positions of both the instrument and targets were established.

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

Total station measurements project coordinates from the local ground network to a target/reflector attached to a geodetic technique instrument as it moves about the instrument's axis, thereby providing the necessary information to locate a single axis. The same procedure is done for the opposing axis of the instrument in the same local reference frame. The point along the azimuth axis that is orthogonal to the elevation axis is the technique's IVP.

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

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

5 Data analysis and results

5.1 Terrestrial survey

5.1.1 Analysis software

After data collection, Spatial Analyzer software was used to generate points and lines via circle- fitting, as described above. This allowed for analysis of the VLBI technique's azimuth axis, elevation axis, and axial offset. Circle-fitting was also used to determine the GNSS station GRP.

Terrestrial observations of the ground network and SGTs were brought from Spatial Analyzer to Star*Net software to be combined with the GNSS observations for rigorous least squares adjustment. The combined geodetic adjustment produced coordinates and variance-covariance information for all surveyed features. Adjustment parameters and results are available in Star*Net ***.LST*** output file.

5.1.2 Topocentric coordinates and covariance

The terrestrial survey was aligned to ITRF2020 (epoch date of survey) using the GNSS observations in a combined geodetic adjustment. AXIS software was used to compile topocentric coordinate estimates with station **KOKB** as the local origin. Complete covariance information for all network stations is available in AXIS .AXS output file.

Surveyed topocentric coordinates, ITRF2020 (epoch 2023/05/13)						
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
KOLB	-52.1988	-354.9779	-0.3969	0.0017	0.0009	0.0007
7298	-18.0216	41.8464	9.2244	0.0002	0.0003	0.0031
7623	2.1064	19.4986	1.2012	0.0002	0.0002	0.0002
Ground network marks						
KOKEE	-29.9248	22.4852	-5.5776	0.0002	0.0002	0.0002
KOLB_MARK	-52.1983	-354.9763	-1.3083	0.0016	0.0008	0.0007
1311 NCMN A	-12.2300	66.1220	-6.8103	0.0002	0.0002	0.0002
NGSA	-19.5138	-10.1572	-2.6486	0.0002	0.0003	0.0002
NGSB	-73.8497	-370.3488	-9.3085	0.0016	0.0008	0.0007
PEACESAT	-7.3609	-10.8237	-5.9951	0.0002	0.0002	0.0002

Table 3: Topocentric Coordinates

5.1.3 Correlation matrix

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

5.1.4 Reference temperature of radio telescope

The international VLBI Service reports a reference temperature of VLBI SGT 7298 of 16.9 degrees Celsius. The reference temperature of radio telescope VLBI SGT 7623 is 17.0 degrees Celsius. At the time of writing, file antenna-

info.txt is available online.
https://raw.githubusercontent.com/anothnagel/antenna-info/master/antenna-info.txt

Thermal expansion corrections were applied to VLBI telescopes 7298 and 7623 using individual antenna parameters and a log of ambient air temperatures taken at the time of survey observations.

7298 20-Meter VLBI antenna parameters (Instrument setup D):
T0 = 16.9 Reference temperature (C).

c_foundation	= 0.000010	Coefficient of expansion of foundation material. Concrete, with 6 hour lag time.
c_pedestal	= 0.000012	Coefficient of expansion of pedestal/antenna material. Steel, with 2 hour lag time.
h_foundation	= 5.490	Dimension of foundation (m).
h_pedestal	= 9.19	Dimension of pedestal (m).

Observed temperatures:

T_foundation	= 13.3	Six hours before optical survey observations.
T_pedestal	= 15.6	Two hours before optical survey observations.

Calculations:
Δh_total = Δh_foundation + Δh_pedestal
Δh_total = [0.000010 * (13.3 - 16.9) * 5.490] + [0.000012 * (15.6 - 16.9) * 9.19]
Δh_total = [-0.00020] + [-0.00014]
Δh_total = -0.00034 meters = -0.34 millimeters

For this set of observations for instrument setup D, a correction of 0.34 millimeters was **added** to the survey height to obtain the reference temperature position.

7623 12-Meter VLBI antenna parameters:
Similarly, the correction for this antenna was calculated as:

Δh_total = Δh_foundation (none) + Δh_pedestal
Δh_total = [0] + [0.000012 * (15.6 – 17.0) * 6.30]
Δh_total = [0] + [-0.00010]
Δh_total = -0.00011 meters = -0.11 millimeters

For this set of observations, 0.10 mm was **added** to the surveyed height to obtain the reference temperature position.

Instrument A:
7298: = -0.00026 meters = -0.26 mm
7623: = -0.00008 meters = -0.08 mm

5.2 GNSS

5.2.1 Analysis software

NGS's OPUS Projects software was used to process and analyze ITRF2020 vectors between stations at the epoch date of survey. As noted, Star*Net software was used to combine the terrestrial and GNSS observations in a rigorous least squares adjustment. The combined geodetic adjustment produced coordinates and variance-covariance information. Adjustment parameters and results are available in Star*Net ***.LST*** output file.

5.2.2 Results

AXIS was used to compile geocentric coordinate estimates from the combined geodetic adjustment. Using the GNSS observations, the survey was aligned to the reference frame ITRF2020 (epoch data of survey). Complete covariance information for all network station is available in AXIS ***.AXS*** output file.

Surveyed geocentric coordinates, ITRF2020 (epoch 2023/05/13)						
STATION	***X(m)***	***Y(m)***	***Z(m)***	***SX(m)***	***SY(m)***	***SZ(m)***
Space geodetic technique stations						
KOKB	-5543838.3647	-2054585.5978	2387810.5483	0.0000	0.0000	0.0000
KOLB	-5543981.5288	-2054582.9872	2387481.5629	0.0010	0.0016	0.0009
7298	-5543837.8608	-2054566.1916	2387852.7873	0.0028	0.0011	0.0012
7623	-5543831.7897	-2054585.4075	2387829.0634	0.0002	0.0002	0.0002
Ground network marks						
KOKEE	-5543835.9778	-2054552.7994	2387829.2768	0.0003	0.0003	0.0004
KOLB_MARK	-5543980.7364	-2054582.6940	2387481.2211	0.0009	0.0016	0.0008
1311 NCMN A	-5543813.3465	-2054563.2830	2387869.2357	0.0002	0.0002	0.0002
NGSA	-5543846.4326	-2054567.7770	2387800.1415	0.0002	0.0002	0.0002
NGSB	-5543986.7405	-2054561.8287	2387463.9674	0.0009	0.0016	0.0008
PEACESAT	-5543839.5379	-2054578.1824	2387798.2637	0.0002	0.0002	0.0002

Table 4: Coordinate estimates for network stations

5.3 Additional parameters

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

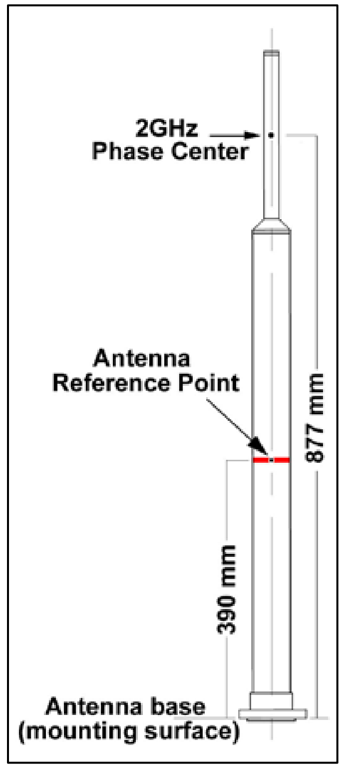
SGT 7298 offset: 0.5181 m +/- 1.7 mm
SGT 7623 offset: 0.0004 m +/- 0.3 mm

For SGT 7298, the International VLBI Service reports an axial offset of 0.5174 m.
For SGT 7623, the International VLBI Service reports an axial offset of 0.0020 m.
At the time of writing, file antenna-info.txt is available online. https://raw.githubusercontent.com/anothnagel/antenna-info/master/antenna-info.txt

Previous surveys conducted by NGS reported the following axial offsets:
7298 offset 2018: 0.5163 m
7298 offset 2014: 0.5189 m

7623 offset 2018: 0.0022 m

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	0.0004	-0.0005	0.5229
KOLB ARP	-0.0007	0.0018	0.9129
KOLB PHASE CTR	0.0004	-0.0001	1.3999

Table 5

Geoid model used
Geoid heights were determined via astronomical leveling from NGSB to TP01 and NGSB to PSAT, holding the xGEOID20B model value at NGSB as fixed. The remaining points were linearly interpolated/extrapolated along the NGSB-PSAT line.

5.4 Transformations

ITRF2020 GNSS vectors were generated to CORS in the surrounding region. The vectors were used in a combined geodetic adjustment to align, or transform, the surveyed local ties to ITRF2020 at the epoch date of survey.

5.5 Description of SINEX generation

AXIS software was used to generate a SINEX file with full variance-covariance matrix information. All stations with DOMES numbers are included in SINEX file **NGSKPGO2305GA.snx.**

The following SINEX file naming convention was used.
XXXNNNNYYMMFV.SNX
Where:
XXX is a three-character organization designation.
NNNN is a four-character site designation.
YY is the year of the survey.
MM is the month of the survey.
F is the frame code (G for global, L for local).
V is the file version.

5.6 Discussion of results

A geodetic least squares adjustment of the observations was conducted using Star*Net. The statistical summary from the adjustment is included. For additional details concerning the adjustment, see Star*Net .LST output file.

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

Iterations              =      3

Number of Stations      =     30

Number of Observations  =    556
Number of Unknowns      =    123
Number of Redundant Obs =    433

Observation   Count    Sum Squares        Error
                         of StdRes        Factor
Coordinates      3         0.000          0.000
     Angles     17        11.948          0.950
 Directions    134        57.083          0.740
  Distances    168       138.661          1.029
Az/Bearings     12         8.208          0.937
    Zeniths    167       125.372          0.982
 Elev Diffs      1         0.000          0.000
 GPS Deltas     54        45.354          1.038

      Total    556       386.626          0.945

      The Chi-Square Test at 5.00% Level Passed
           Lower/Upper Bounds (0.933/1.067)
```

Comparison with IERS computed tie

ITRF2020 (epoch date of survey) computed coordinates were obtained from the IERS. A comparison of the surveyed tie vectors against the computed ties is provided where available.

IERS geocentric computed coordinates, ITRF2020 (epoch 2023/05/13)			
STATION	***X (m)***	***Y (m)***	***Z (m)***
KOKB	-5543838.3647	-2054585.5977	2387810.5483
KOLB	-5543981.5301	-2054582.9921	2387481.5562
7298	-5543837.8630	-2054566.1962	2387852.7850
7623	-5543831.7871	-2054585.4147	2387829.0623

Table 6: IERS computed coordinates

Surveyed tie vs. IERS computed tie NGS 2022 geocentric tie discrepancies			
STATION	***X (mm)***	***Y (mm)***	***Z (mm)***
KOKB	0.0	-0.1	0.0
KOLB	1.3	4.9	6.7
7298	2.2	4.6	2.3
7623	-2.6	7.2	1.1

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

Comparing against the ITRF2020 computed coordinates, the current survey has a maximum tie discrepancy of 7.2 millimeters in the Y 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 ITRF2014 (epoch 2018/06/10). 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 2018)			
Topocentric tie discrepancies			
STATION	*DE (mm)*	*DN (mm)*	*DU (mm)*
KOKB	0.0	0.0	0.0
7298	-0.9	3.2	-2.1
1311 NCMN A	0.2	5.0	-2.4
KOLB	-1.9	2.1	3.5
7623	0.4	1.8	-1.1
NGS A	-0.4	0.6	-0.3
NGS B	-2.1	2.6	3.9

Table 8: 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

Onsite contact:

Christopher Coughlin (Peraton)
ccough01@peraton.com

Offsite contacts:

David Stowers, NASA (GNSS)
David.a.stowers@jpl.nasa.gov

Jerome Saunier, IGN France (DORIS)
Jerome.saunier@ign.fr

Vincent Garcia, IGN France (DORIS)
Vincent.Garcia@cnes.fr

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.

Lodging can be found in Waimea along Rt. 50 and is the shortest drive time to the observatory (approx. 35 minutes).

7 References

7.1 Name of person(s) responsible for observations

Kevin Jordan (Kevin.Jordan@noaa.gov)
National Geodetic Survey
672 Independence Parkway
Chesapeake, VA 23320
Phone: 202-384-6471

Steven Breidenbach (Steve.Breidenbach@noaa.gov)
National Geodetic Survey
15351 Office Drive
Woodford, VA 22580
Phone: 540-737-8572

7.2 Name of person(s) responsible for analysis

Kevin Jordan (Kevin.Jordan@noaa.gov)
National Geodetic Survey
672 Independence Parkway
Chesapeake, VA 23320
Phone: 202-384-6471

Benjamin Erickson (Benjamin.Erickson@noaa.gov)
National Geodetic Survey
15351 Office Drive
Woodford, VA 22580
Phone: 540-373-1243

7.3 Location of observation data and results archive

National Geodetic Survey
672 Independence Parkway
Chesapeake, VA 23320
Phone: 202-384-6471

7.4 Works referenced

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