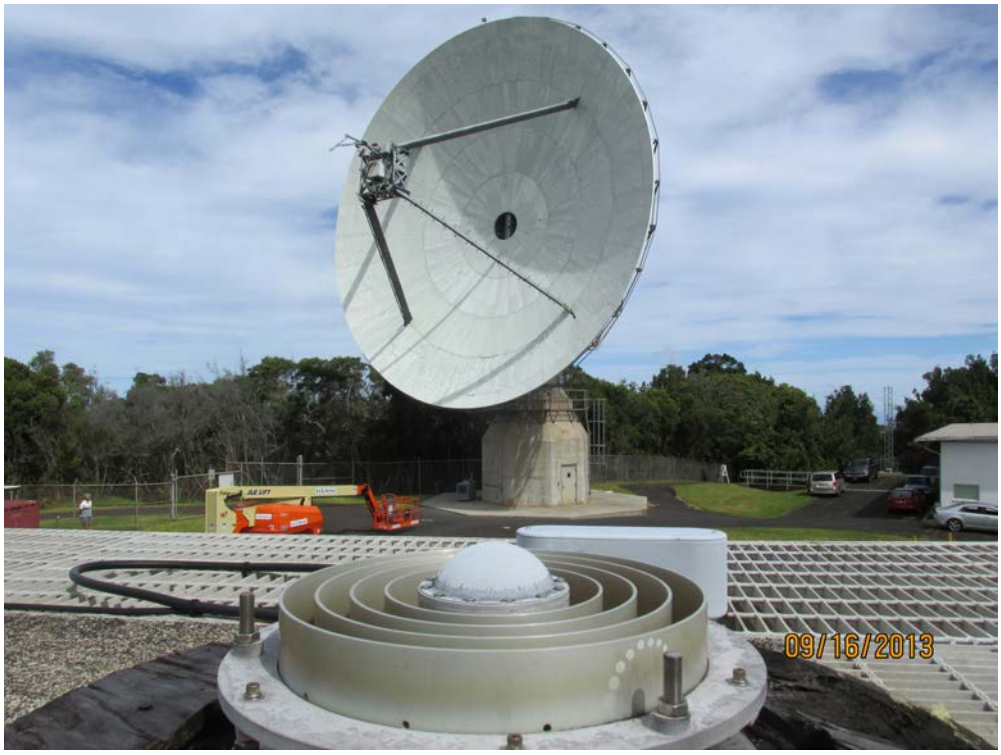
UNITED STATES DEPARTMENT OF COMMERCE
NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE
NATIONAL GEODETIC SURVEY
GEODETIC SERVICES DIVISION
INSTRUMENTATION & METHODOLOGIES BRANCH

LOCAL TIE INFORMATION REPORT
ITRF NETWORK SITE: Kauai, HI (USA)



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Contents

Introduction

In the spirit of scientific cooperation, the U.S. National Oceanic and Atmospheric Administration's (NOAA) National Geodetic Survey (NGS) contributes to future realizations of the International Terrestrial Reference Frame (ITRF) by providing the International Earth Rotation and Reference Systems Service (IERS) with local tie information for geodetic technique instruments co-located at IERS Network Sites considered a priority by that service. Within NOAA, these type surveys are the responsibility of the NGS's IERS Site Survey (ISS) program.

During March, 2014 the NGS ISS program conducted a local tie vector survey at IERS network site KAUAI (Kokee Park Geophysical Observatory). Three space geodetic technique (SGT) instruments are co-located at this site, consisting of a very long baseline interferometry (VLBI) radio telescope, a Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) system and a Global Navigation Satellite Systems (GNSS) station.

This report documents the instrumentation, procedures, data analysis, and local tie information results associated with this survey.

1. Site description

Site Name: Kauai
Country Name: UNITED STATES OF AMERICA
Longitude: 200°19'
Latitude: 22°07'
Tectonic plate: PCFC

SGT Instrument	Name	DOMES#	Description/a.k.a.
GNSS	KOKB	40424M004	VERLOT radar building JPL GPS mark 3028-S
VLBI	7298	40424S007	20M VLBI ANTENNA/AZ-EL CDP STATION 7080
DORIS	KOLB	40424S009	DORIS Antenna Conventional Reference Point

Table 1 - SGT Instruments co-located at the Kauai ITRF site.

2. Instrumentation

2.1. Tacheometers

2.1.1. Description

Two (2) Leica TDM5005
S/Ns: 441698 and 441773
Specifications
Angular measurement uncertainty: ± 0.7"
Distance standard deviation of a single measurement: 1 mm + 2 ppm

2.1.2 Calibrations

Tacheometers calibrated by Leica Geosystem AG Heerbrugg, Switzerland.
Inspection date: 08/15/2008 / 08/20/2008
Both instruments were found to be within factory specifications

2.1.3 Auxiliary Equipment

Wild NL Collimator, S/N: 40145, Pointing accuracy, 1: 200,000
Hygrometer: Omega RH83
Thermometer: Digital thermometer, thermistor sensor, assembled by NGS
Barometer: Leitz AIR-HB-1L, S/N: 1L1890

2.2 GPS units

2.2.1 Receivers

Five (5) Trimble NetR5
P/N: 62800-00
S/Ns: 4619K01307, 4624K01584, 4624K01615, 4624K01631 and 4624K01648
Specifications for Static GPS Surveying
Horizontal: +/- 5 mm + 0.5 ppm RMS
Vertical: +/- 5 mm + 1 ppm RMS

2.2.2 Antennas

Four (4) Topcon GPS/GLONASS/Galileo choke ring antenna, model CR-G3
P/N: 1-044301-01
S/Ns 383-1613, -1614, -1626 and -1628

2.2.3 Analysis software, mode of operation

Post-processing and adjustment were undertaken using NGS's Online Positioning User Service (OPUS) Projects, an interactive web page. OPUS Projects uses NGS's Program for Adjustment of GPS Ephemerides (PAGES) software as an underlying multi-baseline processor.

2.3 Leveling

2.3.1 Leveling instruments

Leica DNA03 digital level, P/N: 723289, S/N: 334271.
Height measurement accuracy: +/-0.3 mm per km, double-run.

2.3.2 Leveling rods

Leica GWCL92 92-cm Invar Bar Code Rod
S/N: 30721
Leica GPCL3 2-m Invar Bar Code Rod
S/N: 30579

2.3.3 Checks carried out before measurements

Instrument collimation test procedures using the Kukkamaki method were undertaken daily, prior to data collection. Leveling rod bubbles were checked daily, prior to use.

2.4 Tripods

Heavy duty wooden surveying tripods were used to support surveying instrumentation centered over all ground network marks, except 1311 MCMN B.

At ground network mark 1311 MCMN B an existing wooden observing stand was refurbished and utilized. A translation plate was affixed to the top of the stand to facilitate centering over the survey mark disk.

2.5 Forced centering devices

At each ground network mark, a Leica GDF321 tribrach was fastened to a tripod/stand, and then plumbed precisely over a survey mark disk using a Wild/Leica NL Collimator. The tribrach was "leveled up" using a GZR3 carrier with longitudinal bubble. That is, the carrier's standing axis was brought into alignment with the local gravity vector using the tribrach's footscrews.

To facilitate precise measurement of the height of instruments/reflectors above each mark, a tribrach adapter was attached to the tribrach to serve as a vertical point of reference. Digital leveling equipment was used to transfer a height difference from the survey mark disk to the vertical point of reference associated with the tribrach adapter. A vertical offset constant of 0.1675m was then added to determine a total height of instruments/reflectors above the mark. This constant represents the distance from the tribrach adapter vertical point of reference to 1) the center of the tilt axis of the tacheometer's telescope and 2) the center of a reflector.

2.6 Targets, reflectors

Five (5) Leica GDH1P reflectors, model #555631
Specifications
Centering of Optics: $\leq \pm$ 0.03mm
Distance Offset: -34.4 mm

One (1) Leica 1.5" Break Resistant Reflector, model#576244
Specifications
Centering of Optics: $\leq \pm$ 0.01mm
Distance Offset: 0.0 $\pm$ 0.01 mm

Except for measurement to KOLB (Ground Mark) and intersection procedure measurements to KOLB and KOKB, all tacheometer observations were made to Leica GPH1P precision reflectors, serving as both target and reflector. The manufacturer-provided offset value of -34.4 mm for the GPH1P was validated prior to the survey.

KOLB (Ground Mark) is located inside the support stanchion for a DORIS antenna, see Figure 6. Due to space constraints created by the stanchion, a Leica 1.5-inch (3.8-cm) break resistant reflector, attached to a fixed centering pin, was used instead of a GPH1P.

To minimize potential loss of precision in distance measurement, care was taken to precisely point all reflectors back to the tacheometer. To that end, reflectors used for radio telescope measurements were affixed to radio-controlled, pan-tilt units which were remotely controlled by the observer after each motion of the radio telescope.

3. Measurement Setup

3.1 Ground network

The ground network at KAUAI consists of three categories of survey marks; main scheme, supplemental and temporary. The main scheme and supplemental marks are monumented for future use. Main scheme marks were tied together in a local coordinate system with repeated and extremely precise horizontal and vertical angle measurements and distance measurements. These marks were used to tie SGT instruments directly to the ground network, and indirectly, to each other. Supplemental marks were precisely positioned relative to the ground network, but did little or nothing to enhance it and were included in this survey for comparison with previous

surveys. Temporary marks were used to facilitate current site survey measurements and were not monumented for use in future surveys.

3.1.1 Listing

Current Survey	DOMES	IERS 4-char code	Current Survey id	Previous Survey (ASTS 2002) Point Name	NGS PID
Main Scheme Marks					
1311 NCMN A	n/a	n/a	NCMN_A	1311 MCMN A	n/a
KOKEE	n/a	7851	KOKE	KOKEE 1961	TU0791
NGS A	n/a	n/a	NGS_A	n/a	n/a
NGS B	n/a	n/a	NGS_B	n/a	n/a
Supplemental Marks					
1311 NCMN B	n/a	n/a	NCMN_B	1311 MCNM B (1993)	n/a
SGT Instrument Reference Marks (IRMs)					
3028-S	40424M004	KOKB	GPS	3028-S GPS (JPL 1987)	n/a
KOLB (ground mark)	n/a	n/a	DRM	n/a	n/a
SGT Conventional Reference Points					
SGP 7298	40424S007	7298	IVP_1	KAUAI SGP 7298	n/a
KOLB	40424S009	KOLB	DRP	DORIS 2002	n/a

Table 2 - Listing of Ground Network Marks, SGT instrument marks, and SGT conventional reference points common to both the current survey and historical surveys conducted at the Kauai ITRF site.

Main-Scheme Marks

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

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.

NGS A - is a masonry “pk” nail set in top of and near the NE 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.

Supplemental Marks

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

Instrument Reference Marks (IRMs)

3028-S – is a 'Dinardo'-type steel plate set in the top of a concrete roof of, and near the northwest corner of a 4-meter tall concrete tower. The mark hosts an Ashtech choke ring antenna model number ASH701945G_M, serial number CR6200342010. At time of survey, there was no radome attached to the antenna. The antenna reference point (ARP) is reported by the International GNSS Service (IGS) to be offset from the reference mark by:
Marker->ARP Up Ecc: 0.0614 m, North Ecc: 0.000 m, East Ecc. (m) : 0.000

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

3.1.2 Maps of Network

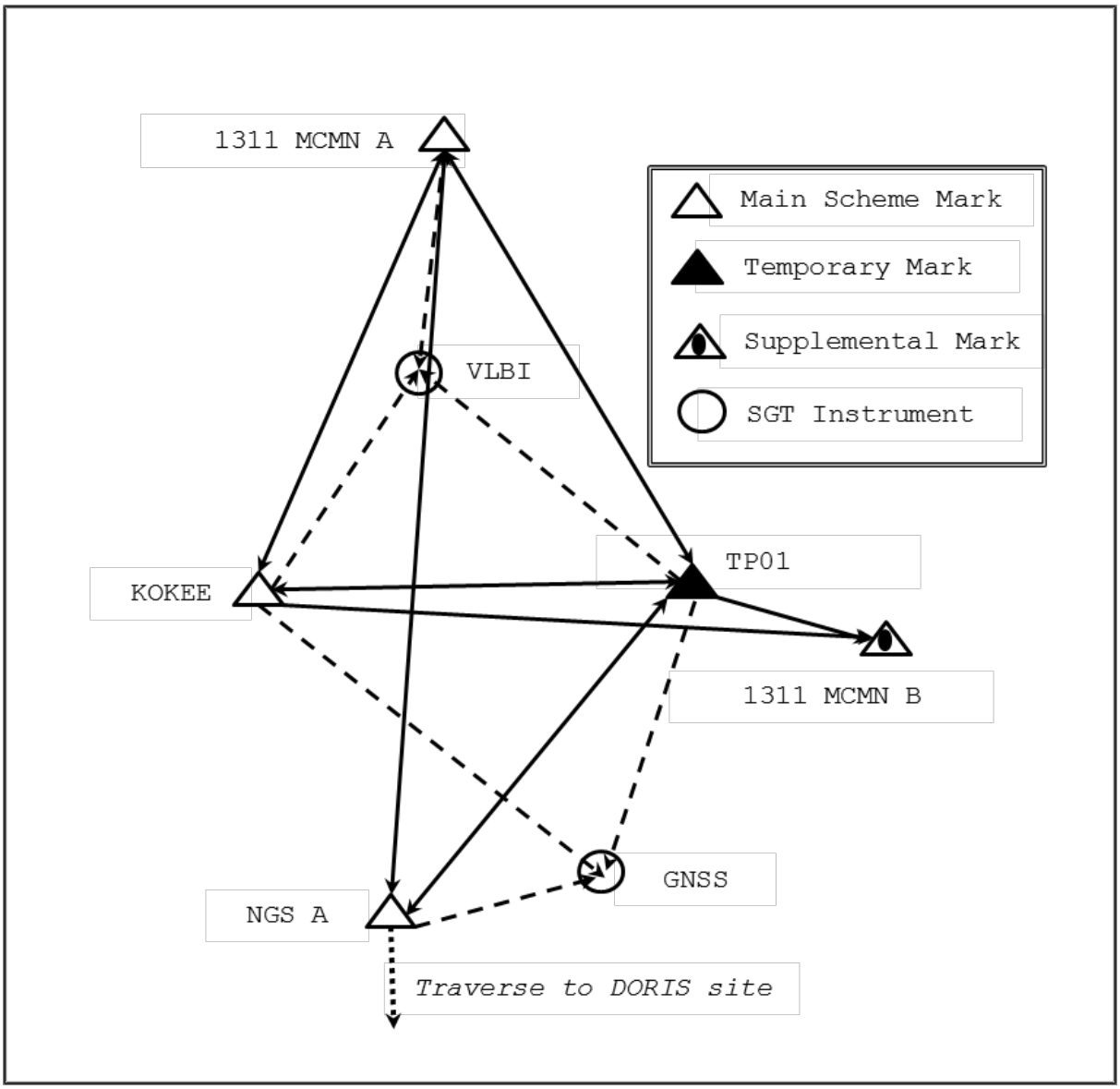

Figure 1 – Map depicting terrestrial survey of ground network at north end of project site, near the VLBI and GNSS instruments.

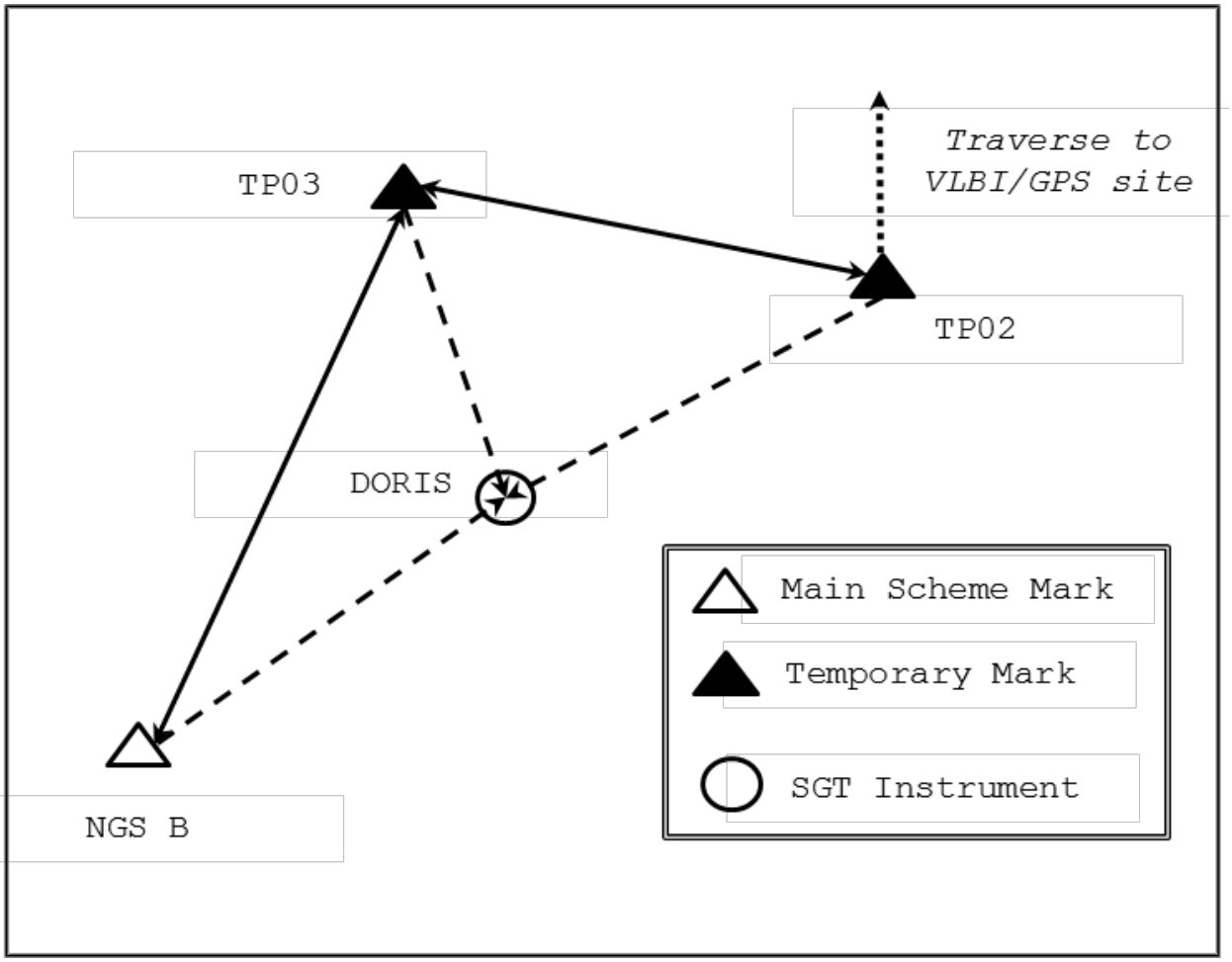

Figure 2 – Map depicting terrestrial survey of ground network at south end of project site, near the DORIS instrument.

3.2 Representation of Technique Reference Points

The conventional reference point (CRP), a.k.a. invariant reference point (IVP), is a theoretical point. For a VLBI antenna, the CRP can be defined as the intersection of the azimuth axis with the common perpendicular of the azimuth and elevation axis (Johnston et al, 2004). For a DORIS antenna, the CRP can be defined as the intersection of the center of the antenna tube with the center of a red stripe encircling it.

3.2.1 VLBI

SGP 7298 - NASA maintains the VLBI radio telescope, which is a 20-m AZEL type antenna. This instrument does not have an associated IRM.

Figure 3 – VLBI 7298 in zenith position, view taken from the approximate location of ground network mark TP01.

The VLBI CRP is not physically accessible, being a theoretical point. Coordinates for the VLBI CRP were determined indirectly by a circle fitting routine. Measurements to the targets were made from main scheme marks KOKEE and 1311 MCMN A and temporary mark TP01. The site log for SGP 7298 is available at the International VLBI Service for Geodesy and Astrometry (IVS) web page: **ftp://ivscc.gsfc.nasa.gov/pub/config/ns/kokee.config.txt**

3.2.2 SLR

No co-located SLR instrument at this site.

3.2.3 GPS

KOKB (a.k.a. GPS in computations and 3028-S) – NASA Jet Propulsion Laboratory maintains the GNSS tracking station. The current GPS antenna is an Ashtech model number ASH701945G_M, serial number CR6200342010. The antenna is centered over IRM KOKB and separated vertically from the mark by a 0.0614 m long centering pin. The IRM is not accessible for direct occupation with conventional survey instrumentation. Coordinates for KOKB were determined during this survey by intersection method from main scheme marks KOKEE and NGS B and temporary mark TP01. The KOKB site log is available at **http://igscb.jpl.nasa.gov/network/site/kokb.html**.

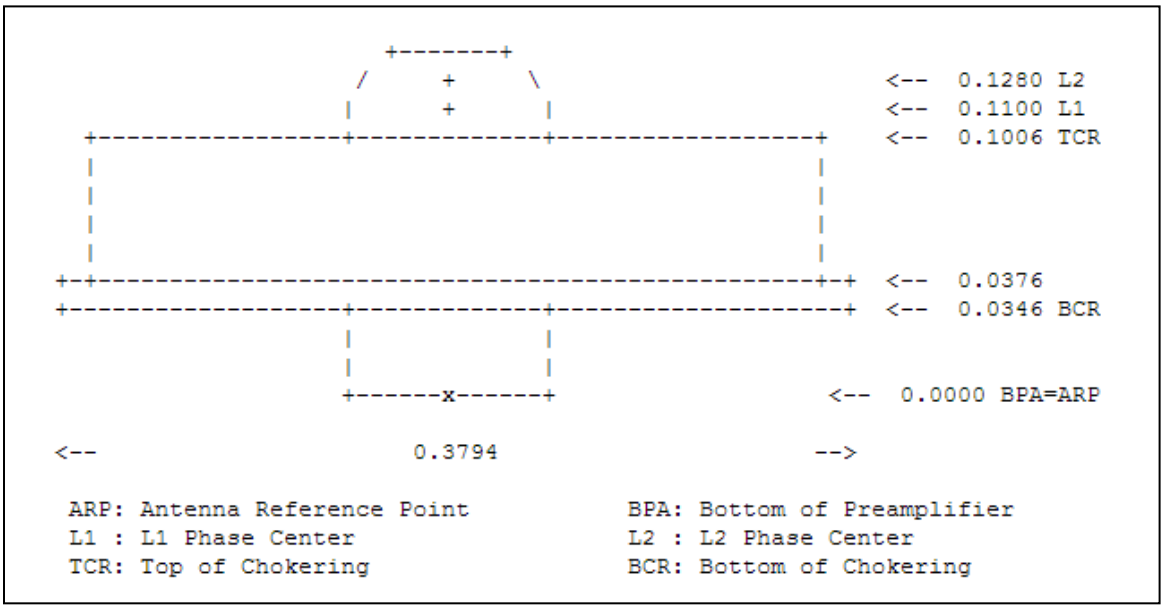

Figure 3 – Dimensional drawing of the GPS antenna type used on IGS Tracking Station KOKB.

Figure 4 – IGS Tracking Station KOKB, view to the south.

3.2.4 DORIS

KOLB (a.k.a. DRP in computations) **–** France's *Institut National de l'information Géographique et forestière* (IGN) maintains the DORIS system. The DORIS CRP (KOLB) is not physically accessible, being a theoretical point. Coordinates for KOLB were determined indirectly in this survey by intersection method. Measurements to KOLB were made from temporary marks TP02 and TP03 and main scheme mark NGS B. The site log for KOLB is available at the International DORIS Service (IDS) web page: http://ids-doris.org/network/sitelogs/station.html?code=KAUAI

Figure 5 – DORIS station KOLB, view to the southwest.

DRM (a.k.a. DRM0 in the SINEX file) – This IRM for DORIS antenna KOLB is located directly below the antenna. It is accessible for direct measurement, but not accessible for occupation with a tacheometer. Coordinates for KOLB were determined by horizontal and vertical angles, and distance measurements from temporary mark TP03 and main scheme mark NGS B.

Figure 6 –KOLB (Ground Mark)

3.2.5 GLONASS

No co-located GLONASS instrument at this site.

4. Observations

4.1 Conventional Survey

The conventional survey consisted of measuring horizontal/vertical angles and distances using a high precision tacheometer, employing traverse and intersection procedures between and/or to all features of interest. All angular and distance measurements were observed a minimum of 3 times with the instrument pointed in both phase I and phase II. Meteorological readings, temperature, barometric pressure and relative humidity, were entered into the tacheometer and an atmospheric correction was applied to each distance measurement. Data collection software GeoObs v1.04.02 was used for recording field measurements and data quality checks. A complete list of unadjusted and adjusted tacheometer field observations consisting of directions, zenith distances, slope distances and instrument/target heights are available in Star*Net output file KOKEE.lst, in a compressed format in Kauai Data Products at the NGS ISS webpage.

4.2 Leveling

Leveling consisted of measuring height difference information between main scheme marks KOKEE, NCMN B, NCMN A and NGS B using a digital bar-code leveling system. Additional leveling was conducted to include temporary marks TP01, TP02 and TP03. All leveling between ground network marks was conducted in accordance with FGCS First-Order, Class I specifications, yielding high precision height differences. Complete lists of unadjusted leveling observations are available in TRANSLEV 4.17 output files kokee.bok and kokee.hgz, in a compressed format in Kauai Data Products at the NGS ISS webpage.

4.3 GPS

GPS data collection consisted of simultaneous and long-session observations, conducted over multiple days providing redundant occupation of ground network marks. GPS data was collected for two purposes; 1) to provide initial coordinates and azimuth for a classical least-squares adjustment of the terrestrial survey, and 2) to produce high-precision 3-dimensional coordinates for aligning the complete terrestrial survey network to ITRF2008(14:081:43200), the epoch date of the survey.

A report detailing the GPS portion of this survey is available in Word file KOKEEGPS.doc, in a compressed format in Kauai Data Products at the NGS ISS webpage.

4.4 General Comments

As noted earlier, determining the local coordinates of the VLBI CRP requires an indirect approach using circle-fitting software. 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 seen 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. Tacheometer measurements transfer coordinates from the local ground network to the targets attached to a telescope as it moves about the telescope axis, thereby providing the necessary information to locate a single axis. The same must be done for the opposing axis of the telescope in the same local coordinate system. The point along the primary axis that is orthogonal to the secondary axis is the conventional reference point of the telescope.

The minimum number of points needed to define a circle, and therefore an axis, is three. The minimum number of measurements needed to extend local coordinates to three points is ten (four horizontal directions, three vertical angles, and three slope distances). Twenty measurements will define two axes and provide local coordinates for the CRP.

In practice, a complex system of precise observations involving three targets secured to the telescope, measurements from three ground network marks, and numerous measurements per axis ensure sub-millimeter results. The CRP for the VLBI instrument was determined in this manner.

Another indirect approach, intersection method, allows SGT instruments to continue operating while the tie to their IRM is made. This approach was used on IGS tracking station KOKB and DORIS station KOLB. The horizontal ties to these points were made by intersection from at least three ground network marks.

Leveled height differences were used as a check of the quality of trigonometric leveling observations between network marks. The ability to compare trig leveling against a standard (differential leveling) while observing the radio telescope targets in the same local reference system provided quality assurance for those observations.

5. Data Analysis and Results

5.1 Terrestrial Survey

5.1.1 Analysis software

Star*Net version 7.2.2.7 was used to perform a classical 3-dimensional least-squares adjustment of the terrestrial data in ITRF2008(14:081:43200). The adjustment used terrestrial observations of all ground network marks and intermediate target points on the VLBI antenna and produced coordinate and variance-covariance information for all, including IRMs for the DORIS and the GPS antenna, and the CRP for the DORIS antenna. The adjustment included differentially leveled height differences between the ground marks. Terrestrial adjustment parameters and results can be found in the Star*Net output file KOKEE.lst. Variance-covariance estimates can be found in the Star*Net output file KOKEE.dmp.

A program developed by the NGS, dmp2vcv.exe, checked the veracity of KOKEE.dmp file's covariance matrix and to translate the point coordinates (including the VLBI's intermediate points) and their variance-covariance values into a new file, KOKEE.vcv, to be used with AXIS.

AXIS 1.07 is circle-fitting, alignment and SINEX-generating software developed by Geoscience Australia (GA). KOKEE.vcv was used as input to compute the VLBI's horizontal and vertical rotational axes relative to the ground network. The program determined the orthogonal offset of the axes and relative coordinates for the VLBI's CRP, aligned the entire survey network to ITRF2008(14/03/21) and generated the survey's SINEX file. Constraints can be found in AXIS input file setup.axs. Circle fitting parameters and results can be found in section 3.0 "Least Squares Estimation" of AXIS output file output.axs.

Files from this section, KOKEE.lst, KOKEE.dmp, KOKEE.vcv, setup.axs and output.axs, are located in a compressed file, KauaiDataProducts.zip, at the NGS ISS webpage.

5.1.2 Topocentric coordinates and covariance

Topocentric coordinates and covariance information from the classical adjustment of the terrestrial data and the circle fitting routines performed using AXIS can be found in section 3.2 "Computed Solution Parameter Summary" of the AXIS output file, output.axs. The file is located in a compressed file, KauaiDataProducts.zip, at the NGS ISS webpage.

5.1.3 Correlation matrix

Computed correlation matrix information can be found in an AXIS output file, NGSKAUA1403GA.snx, an attachment to this report. The original file is located in a compressed file, KauaiDataProducts.zip, at the NGS ISS webpage.

5.2 GPS Observations

NGS's Online Positioning User's Service (OPUS) Projects was used to post-process and analyze GPS data and to compute least-squares, 3-dimensional estimates of mark positions. Resulting adjusted positions can be found in (OPUS) Projects output file network-final.pos. Additional details concerning post-processing parameters and adjustment results of GPS observations can be found in document kokeeGPS.doc. Both files are located in a compressed file, KauaiDataProducts.zip, at the NGS ISS webpage.

5.3 Additional Parameters

5.3.1 DORIS CRP and Antenna Ground Mark Offset Computations

A simple inverse using the geocentric coordinates found in the SINEX file from DRM to KOLB shows an apparent shift from the published IDS coordinates. NGS software INVERS3D was used to compute a 3-dimensional inverse, using coordinates for these points determined this survey. A comparison between the 3-dimensonal offset reported by the IDS and the 3-dimensional offset computed using INVERS3D are provided in Table 3.

	3-D Offset Reported by IDS (m)	3-D Offset Current Survey (m)	Apparent Shift (cm)
dX	0.792	0.7938	+0.2
dY	0.294	0.2926	-0.1
dZ	-0.344	-0.3434	+0.1

Table 3- Comparison between 3-dimensional offsets from DORIS antenna CRP (KOLB) with KOLB (Ground Mark), as reported by the IDS, with the same offset values measured this survey.

Additionally, the INVERS3D computation yielded a height difference (dU) from DRM to KOLB. A comparison between this difference and the height difference reported by the IDS is found in Table 4.

Height above Ground Mark Reported by IDS (m)	Height above Ground Mark Current Survey (m)	Apparent Shift (cm)
0.912	0.9131	+0.1

Table 4 - Comparison between height differences from DRM (ground mark) to KOLB, as reported by the IDS, with the same height difference measured in this survey.

Inverse computation parameters and results are in output file 3DINV_NGS_DRM2KOLB.txt and resides in a compressed format in Kauai Data Products at the NGS ISS webpage.

5.3.2 VLBI Antenna Axis Offset Computation

AXIS 1.07 software computations include an azimuthal/elevation axes offset value for the VLBI antenna. A comparison between the axis offset reported by the IVS and the offset measured in this survey are provided in Table 5.

VLBI CRP:	Axis Offset Reported by IVS (m)	Axis Offset Current Survey (m)	Apparent Shift (mm)
SGP 7298	+0.5185	+0.5189 +/- 0.0008	+0.4

Table 5 - Comparison between axial offset distance for VLBI antenna 7298, as reported by the VLBI Service, with the same offset distance measured this survey.

Axis offset computation results resides in Section 3.16 “Axial Deflection, Azimuth, Orthogonality, and Offset” of the AXIS output file output.axs, located in a compressed format in Kauai Data Products at the NGS ISS webpage.

5.3.3 VLBI Antenna Thermal Expansion Correction Computation

A height correction for the CRP of SGP 7298 was computed based on the following procedure:

i) Compute a mean survey temperature and see to what extent it differs from the reference.
ii) Multiply the CRP height by 0.000012 and by the temperature difference
iii) Correct the CRP height if it is needed.

- **Telescope reference temperature:** +**16.9 ^{O}C** from Antenna Information File Format Version of 2008.04.22 found at http://vlbi.geod.uni-bonn.de/Analysis/Thermal/antenna-info.txt.
- **Estimated fixed axis temperature: +15.5 ^{O}C** (Estimate based on average of highest and lowest air temperatures as reported by KPGO Station Manager Ronald Curtis for the two days of tacheometer observations)
- **Estimated temperature difference** (reference - observed): **+1.4 ^{O}C**
- **Height of elevation axis, concrete foundation: 5.49 m**
  - **Thermal coefficient of expansion: 1.0E-5 m/m ^{O}C**
    See http://vlbi.geod.uni-bonn.de/Analysis/Thermal/antenna-info.txt
- **Height of elevation axis, fixed axis: 9.19 m**
  - **Thermal coefficient of expansion: 1.2E-5 m/m ^{O}C**
    See http://vlbi.geod.uni-bonn.de/Analysis/Thermal/antenna-info.txt

[5,490 mm (1.0×10^{-5} m/ m ^{O}C) + 9,190 mm (1.2×10^{-5} m/m ^{O}C)] $\times$ (+1.4 ^{O}C) = **+0.2 mm**

The correction is provided for informational purposes and was not applied to the VLBI CRP.

5.4 Transformation

Local tie vectors from the terrestrial survey were accurately aligned or transformed from a semi-arbitrary frame to the same frame as the SGT instruments using AXIS 1.07 software. In the alignment sequence, AXIS requires a minimum of three points that are common to both reference frames. These common points are referred to as alignment stations. To align from the arbitrary to the desired reference frame, the coordinates and epoch date of the desired frame are used as input at the alignment stations. The spatial integrity of the terrestrial survey is maintained throughout the transformation process.

ALIGNMENT RESIDUALS

CARTESIAN SYSTEM - CENTROID ORIGIN (METRES)

SITE	UNTRANSFORMED-REFERENCE X(M)	Y(M)	Z(M)	TRANSFORMED-REFERENCE X(M)	Y(M)	Z(M)
NGS_A	0.0178	0.0052	0.0058	0.0011	-0.0005	-0.0000
NGS_B	0.1317	-0.3699	-0.0459	-0.0006	-0.0008	-0.0013
TP02	0.1420	-0.3338	0.0001	0.0004	0.0010	0.0012
GPS	0.0248	0.0178	0.0247	-0.0009	0.0003	0.0001

SITE	UNTRANSFORMED-REFERENCE EAST(M)	NORTH(M)	UP(M)	TRANSFORMED-REFERENCE EAST(M)	NORTH(M)	UP(M)
NGS_A	0.0013	0.0123	-0.0150	0.0009	0.0003	-0.0008
NGS_B	0.3926	-0.0444	-0.0126	0.0005	-0.0016	0.0003
TP02	0.3623	0.0066	-0.0159	-0.0008	0.0014	-0.0003
GPS	-0.0081	0.0340	-0.0180	-0.0006	-0.0002	0.0008

TRANSFORMATION PARAMETERS: ARBITRARY TO GLOBAL (OR REFERENCE SET)

CARTESIAN SYSTEM : CENTROID ORIGIN

VARIANCE FACTOR : 3.77612e-07
SIGMA : 6.14501e-04

TX	TY	TZ	RX	RY	RZ
M	M	M	AS	AS	AS
0.0652	-0.1349	-0.0051	188.90	70.49	-99.20

Table 6 – Parameters and residuals from the AXIS transformation of the terrestrial survey data from an arbitrary frame to ITRF2008 (14:081:43200).

Considering the less than ideal GPS observing environment, the GNSS survey of the alignment stations compared favorably to the terrestrial survey. The favorable comparison and quality indicators internal to the GNSS processing software served to indicate the ITRF2008 coordinates were suitable for the alignment. Table 6 contains residuals and parameters from the transformation sequence. Transformation parameters and results can be found in section 5.2 of the AXIS output file output.axs located in a compressed file, KauaiDataProducts.zip, at the NGS ISS webpage.

5.5 Description of SINEX generation

AXIS 1.07 was used to generate a final solution output file in SINEX format with full variance-covariance matrix information. The following SINEX naming convention, adopted by GSA for local survey data, was also used for this survey.

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

First attempt at a final SINEX file produce a variance-covariance matrix that would not invert. NGS developed a program that tests the veracity of the matrix; whether it will invert and its condition. Using this tool, it was discovered that including some of the network stations in the final SINEX caused it to fail, a result of being ill-conditioned. This has not occurred in previous NGS projects and is a concern. However, just including the techniques in the final SINEX file allowed it to pass. The final SINEX file, NGSKAUA1403GA.snx, is included in Appendix A. The file is also available in a compressed file, Kauai.Data.Products.zip, at the NGS ISS webpage.

5.6 Discussion of Results

Least-Squares Estimates of Terrestrial Observations

A classical geodetic adjustment of terrestrial observations was conducted using software Star*Net 7.2.2.7. The adjustment produced 3-dimensional geodetic coordinates, in a semi-arbitrary local terrestrial frame, for all marks included in the survey, including IRMs and CRPs associated with SGTs KOKB and KOLB and the targets intended for use in determination of the CRP for SGT 7298. Additionally, variance-covariance estimates were computed for all stations included in the adjustment. A statistical summary from the adjustment is included in Table 7. Table 8 provides station coordinate error ellipses, at the 95% confidence level, for the ground network marks and the conventional reference marks for SGTs KOKB (GPS) and KOLB (DRP).

Adjustment Statistical Summary

Iterations	= 3
Number of Stations	= 134
Number of Observations	= 2169
Number of Unknowns	= 610
Number of Redundant Obs	= 1559

Observation	Count	Sum Squares of StdRes	Error Factor
Coordinates	3	0.000	0.000
Angles	23	19.778	1.094
Directions	802	601.446	1.021
Distances	816	514.617	0.937
Az/Bearings	1	0.000	0.000
Zeniths	512	392.500	1.033
Level Data	12	9.081	1.026
Total	2169	1537.422	0.993

The Chi-Square Test at 5.00% Level Passed

Table 7 – Statistical summary from classical adjustment of terrestrial survey.

Station Coordinate Error Ellipses (Meters)
Confidence Region = 95

Station	Semi-Major Axis	Semi-Minor Axis	Azimuth of Major Axis	Elev
NGS_A	0.000245	0.000245	0-00	0.000196
NGS_B	0.000605	0.000568	98-35	0.000689
TP02	0.000657	0.000469	92-10	0.000583
TP03	0.000666	0.000484	77-26	0.000673
KOKE	0.000450	0.000263	70-40	0.000305
NCMN_A	0.000868	0.000257	94-51	0.000242
TP01	0.000514	0.000258	141-33	0.000222
NCMN_B	0.000652	0.000291	153-46	0.000706
GPS	0.000477	0.000380	23-15	0.000256
DRP	0.000914	0.000909	30-06	0.000641
DRM	0.000637	0.000504	84-51	0.000684

Table 8 – Station coordinate error ellipses, at the 95% confidence level, for the ground network marks and the conventional reference marks for SGTs KOKB (GPS) and KOLB (DRP).

For additional details concerning the classical adjustment of the terrestrial survey, see Star*Net output file kokee.lst, located in a compressed file, Kauai.Data.Products.zip, at the NGS ISS webpage.

Least-Squares Estimates of CRPs`

AXIS 1.07software was used to produce coordinates and variance-covariance estimates for SGT 7298 CRP. A modified output file from the classical geodetic adjustment, containing coordinates and associated variance-covariance estimates for targets affixed to the VLBI antenna, was used as input. AXIS performed 3-dimensional arc fitting to compute multiple axes in space, which were in turn used to estimate the CRP for SGT 7298. Table 9 contains statistics from the least squares solution. For additional details, see AXIS output file, output.axs, Section 3. LEAST SQUARES ESTIMATION located in a compressed file, KauaiDataProducts.zip, at the NGS ISS webpage

LEAST SQUARES SOLUTION		
# OF TARGETS	:	18
# OF IVP (a.k.a. CRP) ESTIMATES	:	3
# OF COORDINATE-OBSERVATIONS	:	369
# OF UNKNOWNS	:	150
# OF CONDITIONS	:	264
# OF CONSTRAINTS	:	42
# OF ADD. CONSTRAINTS	:	72
# OF CONSTRAINTS TOTAL	:	114
DEGREES OF FREEDOM	:	597
ITERATIONS TO COMPLETE	:	2
MAXIMUM RESIDUAL (METRE)	:	0.00202
VARIANCE (CONDITIONS)	:	2.30573
VARIANCE (CONSTRAINTS)	:	0.23859
VARIANCE (APRIORI)	:	0.00000
VARIANCE FACTOR	:	2.54432
SIGMA	:	1.59509

Table 9 – Statistical summary from the AXIS adjustment of VLBI targets.

Final Coordinate Listing

AXIS 1.07 software was used to compute final coordinate estimates, aligned to reference frame ITRF 2008 (14:081:43200), for almost all main scheme ground network marks, SGT IRMs and CRPs associated with this survey, see Table 10. Including main scheme ground network marks NCMN_A and NGS_B caused the variance-covariance matrix to be ill-conditioned. Final coordinates and variance-covariance matrix information is contained in SINEX format file NGSKAUA1403GA.snx found in a compressed format in Kauai Data Products at the NGS ISS webpage.

CARTESIAN COORDINATES - EARTH CENTRE ORIGIN (METRES) - COFACTOR

SITE	X	Y	Z	SX	SY	SZ
KOKB	-5543838.2796	-2054586.1711	2387810.2610	0.0001	0.0001	0.0002
DRM0	-5543980.6464	-2054583.2688	2387480.9293	0.0004	0.0004	0.0003
KOLB	-5543981.4402	-2054583.5615	2387481.2727	0.0002	0.0003	0.0003
7298	-5543837.7756	-2054566.7659	2387852.4967	0.0001	0.0002	0.0002
NCMN_A	-5543813.2646	-2054563.8576	2387868.9447	0.0002	0.0002	0.0001
NCMN_B	-5543818.7187	-2054610.3736	2387821.8271	0.0004	0.0002	0.0003
KOKEE	-5543835.8921	-2054553.3754	2387828.9885	0.0000	0.0001	0.0001
NGS_A	-5543846.3459	-2054568.3514	2387799.8538	0.0001	0.0001	0.0002
NGS B	-5543986.6474	-2054562.4032	2387463.6769	0.0001	0.0001	0.0002

Table 10 – final coordinate estimates aligned to reference frame ITRF 2008(14:081:43200) for all main-scheme ground network marks, SGT IRMs and SGT CRPs.

NGS program INVERS3D was used to compute local tie vectors using SGT final coordinates taken from SINEX file NGSKAUA1403GA.snx. Local tie vector information is provided in Table 11. SINEX file NGSKAUA1403GA.snx and INVERS3D file 3DINV_NGS_KOKB2SGT.txt reside in a compressed "zip" file under Kauai Data Products at the NGS ISS webpage.

Current Tie Vector

KOKB to 7298

DX =	0.5040 m	DN =	41.8432 m
DY =	19.4052 m	DE =	-18.0207 m
DZ =	42.2357 m	DU =	9.2234 m

KOKB to KOLB

DX =	-143.1606 m	DN =	-354.9795 m
DY =	2.6096 m	DE =	-52.1966 m
DZ =	-328.9883 m	DU =	-0.4007 m

Table 11 – Local tie-vectors determined during the current survey, aligned to ITRF2008 (14/03/21). The vectors emanate from the IGS tracking station (KOKB) IRM.

Local Tie Vector Comparisons: Survey-derived Versus IERS-derived

Table 12 contains ITRF2008(14:081:43200) coordinates for the three SGT instruments extracted from the IERS website, **http://itrf.ign.fr/site_info_and_select/solutions_extraction.php**

CARTESIAN COORDINATES - EARTH CENTRE ORIGIN (METRES)

SITE	X	Y	Z	SDEV	SDEV	SDEV
KOKB	-5543838.2770	-2054586.1712	2387810.2585	0.0013	0.0008	0.0009
7298	-5543837.7837	-2054566.7712	2387852.5001	0.0013	0.0013	0.0010
KOLB	-5543981.4426	-2054583.5678	2387481.2673	0.0020	0.0019	0.0015

Table 12 – ITRF2008(14:081:00000) extracted from IERS website

Local tie vectors derived from SGT IRM and CRP coordinates determined in this survey (Table 11) were compared against local tie vectors derived from SGT IRM and CRP coordinates extracted from the IERS ITRS Product Center web site (Table 13). The results from this comparison are included in Table 14. NGS program INVERS3D was used to compute local tie vectors, the output of which is found in 3DINV_NGS_KOKB2SGT.txt. Local tie vector computations are included in INVERS3D output file 3DINV_NGS_KOKB2SGT.txt resides in a compressed "zip" file under Kauai Data Products at the NGS ISS webpage.

Inter-technique Vector

	KOKB to 7298		
DX =	0.4933 m	DN =	41.8442 m
DY =	19.4000 m	DE =	-18.0195 m
DZ =	42.2416 m	DU =	9.2366 m
	KOKB to KOLB		
DX =	-143.1656 m	DN =	-354.9847 m
DY =	2.6034 m	DE =	-52.1926 m
DZ =	-328.9912 m	DU =	-0.3955 m

Table 13 – ITRF2008(14:081:00000) vectors derived from IERS website extraction above.

Table 14 shows apparent change in vectors that were derived from the IERS website.

Current Tie Vector – Inter-technique Vector

	KOKB to 7298		
DX =	0.0107 m	DN =	-0.0010 m
DY =	0.0052 m	DE =	-0.0012 m
DZ =	-0.0059 m	DU =	-0.0132 m
	KOKB to KOLB		
DX =	0.0050 m	DN =	0.0052 m
DY =	0.0062 m	DE =	-0.0040 m
DZ =	0.0029 m	DU =	-0.0052 m

Table 14 – Vectors from the current site survey minus vectors derived from coordinates extracted from the IERS website.

5.7 Comparison with Previous Surveys

Local Vector Comparisons: Current survey-derived versus previous survey-derived

Allied Signal Technology Services Corp. (ASTS) conducted a local-tie survey at the KAUAI IERS site in November 2002. The classical adjustment of the 2002 ASTS terrestrial survey included observations from other surveys conducted at the site in 1989, 1993 and 1996.

To compare the internal results of the terrestrial surveys without regard to reference frame, the current survey was aligned to the former using AXIS 1.07 software. During the alignment process, it was discovered that four of six available common points showed a very high degree of compatibility between the current and former surveys:

SITE	EAST(M)	NORTH(M)	UP(M)
3028-S GPS (a.k.a. GPS or KOKB)	-0.0006	0.0020	0.0003
KOKEE 1961 (a.k.a. KOKE or KOKEE)	-0.0003	-0.0001	0.0001
1311 NCMN A (a.k.a. NCMN_A)	0.0001	-0.0009	0.0005
KAUAI SGP 7298 (FINAL) (a.k.a. 7298 or IVP_2)	0.0007	-0.0010	-0.0008

Including the other two points resulted in higher alignment residuals and so they were not used. However, they do appear in Table 15, along with their discrepancies. Apparent changes in the estimated relative positions are reported in Table 13 below.

2002 ASTS Vector from **3028-S GPS (JPL 1987)** to:	2014 NGS Vector from **KOKB** to:	Apparent Change (cm)
1311 NCMN A	**NCMN A**	
dX: 25.007 m dN: **66.115 m**	dX: 25.0080 m dN: **66.1182 m**	dN: **0.3**
dY: 22.310 m dE: **-12.229 m**	dY: 22.3111 m dE: **-12.2301 m**	dE: **-0.1**
dZ: 58.685 m dU: **-6.800 m**	dZ: 58.6877 m dU: **-6.8002 m**	dU: **0.0**
1311 NCMN B (1993)	**NCMN B**	
dX: 19.555 m dN: **14.457 m**	dX: 19.5614 m dN: **14.4553 m**	dN: **-0.2**
dY: -24.200 m dE: **29.487 m**	dY: -24.2020 m dE: **29.4914 m**	dE: **0.4**
dZ: 11.570 m dU: **-4.838 m**	dZ: 11.5663 m dU: **-4.8440 m**	dU: **-0.6**
KOKEE 1961	**KOKE**	
dX: 2.383 m dN: **22.483 m**	dX: 2.3835 m dN: **22.4850 m**	dN: **0.2**
dY: 32.794 m dE: **-29.922 m**	dY: 32.7945 m dE: **-29.9223 m**	dE: **0.0**
dZ: 18.728 m dU: **-5.573 m**	dZ: 18.7301 m dU: **-5.5728 m**	dU: **0.0**
DORIS 2002*	**DRM**	
dX:-142.362 m dN:**-354.960 m**	dX:-142.3361 m dN:**-354.9784 m**	dN: **-1.8**
dY: 2.896 m dE: **-52.188 m**	dY: 2.9157 m dE: **-52.1972 m**	dE: **-0.9**
dZ:-329.312 m dU: **-1.308 m**	dZ:-329.3448 m dU: **-1.3496 m**	dU: **-4.2**
DORIS 2002	**DRP**	
dX:-142.362 m dN:**-354.960 m**	dX:-143.1299 m dN:**-354.9791 m**	dN: **-1.9**
dY: 2.896 m dE: **-52.188 m**	dY: 2.6230 m dE: **-52.1986 m**	dE: **-1.1**
dZ:-329.312 m dU: **-1.308 m**	dZ:-329.0015 m dU: **-0.4366 m**	dU: **87.1***
KAUAI SGP 7298 (FINAL)	**7298**	
dX: 0.499 m dN: **41.839 m**	dX: 0.4987 m dN: **41.8424 m**	dN: **0.3**
dY: 19.401 m dE: **-18.018 m**	dY: 19.4022 m dE: **-18.0197 m**	dE: **-0.2**
dZ: 42.234 m dU: **9.228 m**	dZ: 42.2372 m dU: **9.2295 m**	dU: **0.2**

*NOTE: The 2002 ASTS adjustment report indicates measurements were made to KOLB (DORIS CRP) with no mention of measurements to DRM (DORIS ground mark). Inverse computations from KOKB to KOLB, when compared to the current survey, show a 0.861-meter dU discrepancy, suggesting that the ASTS measurements were actually made to KOLB's ground mark (DRM).

Table 15 – Comparison of local tie vectors measured during the 2002 ASTS survey with those determined during the 2014 NGS survey. The two surveys were aligned to each other for this comparison.

Because the specifics of the 2002 ASTS reference frame are unknown, no comparison could be made between vectors of the two surveys in an absolute sense.

6. Planning Aspects

The primary contact for information concerning previous site survey efforts at KPGO and current information regarding geodetic technique instruments at this site is NASA employee James Long. Mr. Long's contact information is:'

Jim Long
NASA Goddard Space Flight Center
FMD Engineering Branch, Code 224
Phone: 301-286-9836
Email: james.l.long@nasa.gov

Establish a point-of-contact (POC) at KPGO to coordinate access to the secured site and schedule time on the VLBI instrument.
At the time of the current survey, the onsite POC at KPGO was:

Ron Curtis
KPGO Station Manager, NASA/SCNS
ITT Exelis
Tel: 808-335-6495
email: ronald.curtis@exelisinc.com

Recommendations

Coordinate in advance with the on-site technicians to take advantage of radio telescope maintenance down time. Site personnel drives the radio telescope under survey team direction during observations.

7. References

Axel Nothnagel (2009) Conventions on thermal expansion modelling of radio telescopes for geodetic and astrometric VLBI; Journal of Geodesy, Vol. 83(3), 787-792, DOI: 10.1007/s00190-008-0284-z

Johnston, G., Dawson, J. and Naebkhil, S., 2004. The 2003 Mount Stromlo Local Tie Survey. *Geoscience Austrailia Record*, 2004/20, 25pp. *Available online: http://www.ga.gov.au/image_cache/GA5653.pdf*

7.1 Name of person responsible for observations

Kendall Fancher
National Geodetic Survey
15351 Office Drive
Woodford, VA 22580
Phone – (540) 373-1243
Email – Kendall.Fancher@noaa.gov

7.2 Name of person(s) responsible for analysis

Kendall Fancher (Kendall.Fancher@noaa.gov)
Steven Breidenbach (Steven.Breidenbach@noaa.gov)
Charles Geoghegan (Charles.Geoghegan@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
Instrumentation & Methodologies Branch
15351 Office Drive
Woodford, VA 22580
Phone – (540) 373-1243
http://www.ngs.noaa.gov/corbin/iss/index.shtml

Attachment: Sinex Format File NGSKAUA1403GA.snx

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 CONTACT            Kendall Fancher, 15351 Office Drive, Woodford, VA 22580 USA
 SOFTWARE           axis version 1.07
 HARDWARE           Dell Latitude
 INPUT              Terrestrial Survey Solution
-FILE/REFERENCE
+FILE/COMMENT
* axis software by John Dawson Geoscience Australia
-FILE/COMMENT
+SITE/ID
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 DRM0  A 40424M000 C DORIS (Ground Mark)    -159 39 55.6  22  7 23.0  1166.1
 KOLB  A 40424S009 C DORIS Starec antenna r -159 39 55.6  22  7 23.0  1167.0
 7298  A 40424S007 C 20m VLBI antenna refer -159 39 54.4  22  7 35.9  1176.6
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 DRM0  A    1 DRM0  A    1 14:081:00000 14:082:00000 --- 14:081:43200
 KOLB  A    1 KOLB  A    1 14:081:00000 14:082:00000 --- 14:081:43200
 7298  A    1 7298  A    1 14:081:00000 14:082:00000 --- 14:081:43200
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+SOLUTION/EPOCHS
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+SOLUTION/STATISTICS
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 NUMBER OF UNKNOWNS                                12
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+SOLUTION/ESTIMATE
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     2 STAY   KOKB  A    1 14:081:43200 m    2 -2.05458617108855e+06 8.67907e-05
     3 STAZ   KOKB  A    1 14:081:43200 m    2  2.38781026095871e+06 1.65019e-04
     4 STAX   DRM0  A    1 14:081:43200 m    2 -5.54398064642296e+06 4.33936e-04
     5 STAY   DRM0  A    1 14:081:43200 m    2 -2.05458326882458e+06 3.69484e-04
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