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
IERS NETWORK SITE: Mauna Kea, 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 July, 2015 NGS conducted a local tie vector survey at IERS network site Mauna Kea (Mauna Kea VLBA Observatory). Two space geodetic technique (SGT) instruments are co-located at this site, consisting of a radio telescope used for very long baseline interferometry (VLBI) 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 : Mauna Kea

Country Name : UNITED STATES OF AMERICA

Longitude : E 204° 33'

Latitude : N 19° 48'

Tectonic plate : PCFC

SGT Instrument	Name	DOMES#	Description/a.k.a.
GPS	MKEA	40477M001	GPS MARKER
VLBI	7617	40477S001	25-M VLBA antenna reference point

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

2. Instrumentation

2.1. Tacheometers

2.1.1. Description

Leica TDM5005
S/N: 441773
<u>Specifications</u>
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: 08/20/2008
The instrument was 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

Trimble NetR5
P/N: 62800-00
S/Ns: 4024K01590, 4624K01584, and 4624K01583
<u>Specifications for Static GPS Surveying</u>
Horizontal: +/- 5 mm + 0.5 ppm RMS
Vertical: +/- 5 mm + 1 ppm RMS

2.2.2. Antennas

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

2.2.3. Analysis software, mode of operation

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

2.3. Leveling

2.3.1. Leveling Instruments

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

2.3.2. Leveling Staffs

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 procedure, were undertaken daily, prior to data collection. Leveling rod bubbles were checked daily, prior to use.

2.4. Tripods

Leica Geosystems type GST 120-9 surveying tripods were used to support surveying instrumentation centered over all ground network marks.

2.5. Forced Centering Devices

At each ground network mark, a Leica GDF321 tribrach was fastened to a tripod, then plumbed precisely over a survey mark disk using a 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. To determine a total height of instruments/reflectors above the mark, an offset constant of 0.1675m was added to the leveled height difference. The 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

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

Leica GRT144, Carrier with Stub
Centering Accuracy: ± 1.0 mm

Except for intersection procedure measurements to MKEA, 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. Reflectors were affixed to tribrachs using GRT144 carriers.

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 to point reflectors back to the tacheometer after each motion of the radio telescope.

3. Measurement Setup

3.1. Ground Network

The ground network at MKEA consists of two categories of survey marks; main scheme and temporary. Main scheme marks are monumented for future use. Main scheme marks were tied together in a local coordinate system using high precision horizontal angles and distance measurements. Height differences between the marks were determined by precise leveling techniques. These marks were used to tie SGT instruments directly to the ground network, and indirectly, to each other. The ground network included one temporary mark (TP01), which was used to facilitate intersection measurements to the GPS tracking station MKEA. This temporary mark was not permanently monumented for use in future surveys.

3.1.1. Listing

Current Survey	DOMES	IERS 4-char code	Current Survey id	Previous (ASTS) Survey Point Name	NGS PID
Main Scheme Marks					
7617 RM1	n/a	n/a	RM01	7617 RM1	n/a
7617 RM2	n/a	n/a	RM02	7617 RM2	n/a
7617 RM3	n/a	n/a	RM03	7617 RM3	n/a
SGT Instrument Reference Marks					
MKEA	40477M001	MKEA	MKEA	n/a	n/a
SGT Conventional Reference Points					
7617	40424S007	7617	7617	7617	n/a

Table 2 – Listing of Main Scheme Marks, SGT Instrument Reference Marks, and SGT Conventional Reference points common to both the current NGS survey and historical surveys associated with the Mauna Kea ITRF site.

<u>Main-Scheme Marks</u>

7617 RM1 **-** is a dimple mark set into and near the top center of a stainless steel rod driven to an unknown depth and enclosed by a generic aluminum log cap stamped 7617 RM 1.

Figure 1 – Overhead close-up view of 7617 RM1

7617 RM2 **-** is a dimple mark set into and near the top center of a stainless steel rod driven to an unknown depth and enclosed by a generic aluminum log cap stamped 7617 RM 2.

Figure 2 – Overhead close-up view of 7617 RM2

*7617 RM3***-** is a dimple mark cast into the top center of a NASA survey disk epoxied into a drill hole in an outcropping of lava stamped
7617 RM 3 JUL 96.

Figure 3 – Overhead close-up view of 7617 RM3

Instrument Reference Marks

MKEA **–** The monument is a 4 inch diameter steel pipe cemented 11 foot below ground and protruding 4 foot above ground with a ¾ inch bolt welded to a screw cap on top of the mount. The monument hosts a Javad chokering antenna model number JAVRINGANT_DM NONE, serial number 00983. At time of survey, a SCIGN radome was attached to the antenna. The Instrument Reference Mark is reported by the International GNSS Service (IGS) to be coincident with the antenna reference point (ARP).

Figure 4 – SGT MKEA, the IRM associated with SGT MKEA is coincident with the ARP.

3.1.2. Map of Network

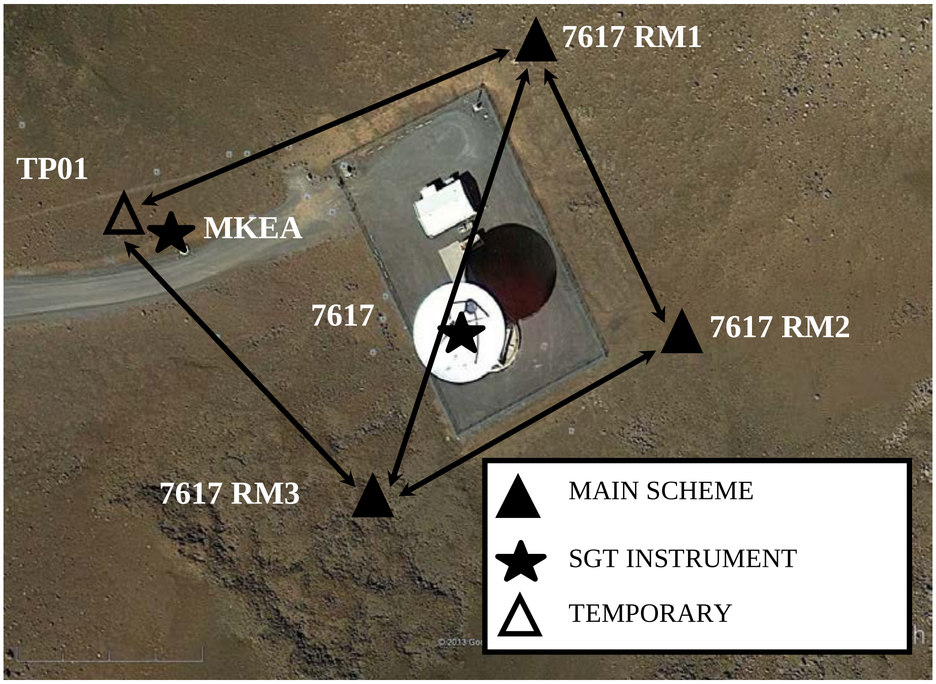

Figure 5 – Aerial image of the MKEA ITRF site depicting the spatial relationship of the co-located SGT instruments, main scheme network marks and temporary marks.

3.2. Representation of Technique Reference Points

The conventional reference point (CRP), a.k.a. invariant reference point, is a theoretical point. For the MKEA 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).

3.2.1. VLBI

7617- The National Radio Astronomy Observatory operates the Very Long Baseline Array (VLBA). SGT 7617 is one of 10 instruments comprising the VLBA. This instrument is used for a variety of astronomic science including periodic VLBI measurements. SGT 7617 is a 25-m AZEL type antenna. This instrument does not have an associated IRM.

Coordinates for the CRP associated with SGT 7617were determined indirectly this survey by means of a circle fitting routine, using horizontal/vertical angle and distance measurements to targets affixed to the antenna during different rotational sequences.

Figure 6 – SGT 7617 view to the east.

3.2.2. GPS

MKEA- The National Aeronautical & Space Administration's Jet Propulsion Laboratory operates this GNSS tracking station. The station is included in the International GNSS Service (IGS) tracking network. The antenna type at time of the current NGS survey was A Javad model JAVRINGANT_DM + NONE (serial number 00983). At the time of the current NGS survey there was a SCIGN dome attached to the antenna. The antenna is reported to be centered horizontally over the IRM with a zero vertical offset and is coincident with the ARP. Without removal of the antenna, the IRM is not accessible for direct occupation of survey instrumentation.

Figure 6 – SGT MKEA view to the east.

Coordinates for the IRM associated with MKEA were determined this survey by intersection method from main scheme marks 7617 RM1, 7617 RM3 and a temporary mark (TP01). A site log for MKEA is available at the IGS web page: https://igscb.jpl.nasa.gov/igscb/station/log/mkea_20150421.log

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 and incorporated double centering, or measuring in both phase I and phase II. Meteorological corrections were input into the tacheometer and applied at time of field measurement. Data collection software GeoObs v1.04.02 was used for recording field measurements and field level 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 MKEA.lst. All Star*Net output files referenced in this report can be found in a compressed file under "Mauna Kea Data Products" at: **http://www.ngs.noaa.gov/corbin/iss/index.shtml**

4.2. Leveling

A closed level loop was run, beginning at main scheme mark 7617 RM1 and through main scheme marks 7617 RM2, 7617 RM3 and the IRM associated with SGT MKEA. Measurements to the IRM associated with SGT MKEA were made by “zeroing” in on the bottom of the GPS antenna’s preamp, which is coincident with the vertical component of the IRM. All intermediate sections were double run. Leveling data was collected for the purpose of determining high precision height difference information referenced to the geoid. The measured height differences were incorporated into a classical 3-dimensional adjustment of the terrestrial data.

4.3. GPS

GPS data was collected for the purpose of determining high precision 3-dimensional IGS 2008 (2015/07/12) coordinates for ground network marks (7617 RM1, 7617 RM2 and 7617 RM3) and the IRM associated with SGT MKEA. GPS data collection consisted of simultaneous and long duration observations, conducted over multiple days providing redundant occupation of main scheme network marks. Ultimately the coordinates determined from an adjustment of the GPS data were constrained in the transformation, or realignment of the terrestrial survey from a local arbitrary reference frame to ITRF 2008 (2015/07/12).

4.4. General Comments

As noted earlier, determining the local coordinates of the VLBI CRP was achieved using an indirect approach. The “circle fit” theory is straight-forward. A point, as it revolves about an axis, scribes a perfect arc. The arc defines a perfect 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 project coordinates from the local ground network to a target attached to a telescope as it moves about the telescope axis, thereby providing the necessary information to locate a single axis. The same procedure must be done for the opposing axis of the telescope in the same local reference frame. The point along the primary axis that is orthogonal to the secondary axis is the CRP associated with the SGT.

In practice, a complex system of precise observations involving three targets secured to the telescope, measurements from at least two ground network marks, and numerous measurements per axis serve to ensure a millimeter level of positional precision is achieved. The CRP associated with SGT 7617 was determined in this manner

Another indirect approach, the intersection method, was used to determine the horizontal coordinates of the IRM associated with SGT MKEA. The intersection method allows for determination of the IRM without removal of the antenna/dome combination from the monument, avoiding an interruption to GNSS data collection. Intersection measurements to the IRM associated with SGT MKEA were taken from two main scheme marks (7617 RM1 and 7617 RM3) and a temporary mark (TP01).

5. Terrestrial Survey

5.1. Analysis software

Commercially available least squares adjustment software Star*Net (version 8,1,2,990) was used to perform a classical 3-dimensional adjustment of the terrestrial data. Measurements included in the adjustment consisted of terrestrial observations of all ground network marks, intersection stations, and intermediate target points affixed to the VLBI antenna, producing local coordinate and variance-covariance information for; all ground network marks, all VLBI intermediate targets and the IRM associated with SGT MKEA. The adjustment included leveled height differences between the main scheme marks and to the IRM associated with SGT MKEA. Terrestrial adjustment parameters and results can be found in Star*Net output file MKEA.lst. Terrestrial adjustment variance-covariance estimates can be found in the Star*Net output file MKEA.dmp.

AXIS 1.07 software, developed by Geoscience Australia (GA), was used to perform 3-dimensional arc fitting to compute a number of axes in space, which were in turn used to estimate the CRP associated with SGT 7617. A Star*Net output file (MKEA.dmp) containing coordinates and variance-covariance estimates for intermediate targets affixed to the VLBI antenna was used as input. Circle fitting 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. All AXIS output files referenced in this report can be found in a compressed file under "Mauna Kea Data Products at: **http://www.ngs.noaa.gov/corbin/iss/index.shtml**

5.1.2. Topocentric Coordinates and Covariance

Topocentric coordinates and covariance information, from the classical adjustment of the terrestrial data, for main scheme network marks, VLBI targets and the IRM associated with SGT MKEA can be found in section 2.1 "SOLUTION PARAMETER SUMMARY" and section 2.2 SOLUTION VARIANCE COVARIANCE MATRIX REDUCTION" in AXIS output file output.axs.

5.1.3. Correlation Matrix

Reduced correlation matrix information for the main scheme network marks, the CRP associated with SGT 7617 and the IRM associated with SGT MKEA can be found in section 4.19 "COMPUTED SOLUTION PARAMETER SUMMARY" in AXIS output file output.axs.

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.

5.3. Additional Parameters

5.3.1. VLBI Antenna Axis Offset Computation

AXIS software computations include an azimuthal/elevation axes offset value for the VLBI antenna. A comparison between the axis offset reported by the International VLBI Service (IVS) and the offset measured this survey are provided in Table 3.

CRP for:	Axis Offset Reported By IVS (m)	Axis Offset computed by NGS (m)	Difference (mm)
7617	2.1343 +- 0.0005	2.1342 +/- 0.0003	-0.0001

Table 3 - Comparison of axial offset distance for VLBI antenna 7617, as reported by the IVS, against the offset distance measured during the current NGS survey.

Axis offset computation results can be found in section 4.7 "IVP/TOUCH/INTERSECT PARAMETER VALUES AND THEIR PRECISION" of the AXIS output file output.axs.

5.4. Transformation

Tie vectors from the terrestrial survey were accurately aligned, or transformed, from a local arbitrary frame to the same frame as the SGT instruments using AXIS software . For the alignment, AXIS requires coordinates, in the desired reference frame and epoch date, at a minimum of three co-observed sites (7617 RM1, 7617 RM2, 7617 RM3 and MKEA). The spatial integrity of the terrestrial survey is maintained throughout the transformation process.

Transformation parameters and results can be found in section 3. "APRIORI FRAME ALIGNMENT " in the AXIS output file output.axs.

5.5. Description of SINEX generation

AXIS 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

Axis generated SINEX file ***ngsMKEA1507ga.snx*** is included in Appendix A.

5.6. Discussion of Results

Least-Squares Estimates of Terrestrial Observations

A classical 3-dimensional adjustment of terrestrial observation was conducted using Star*Net. The adjustment produced geodetic coordinates, in a local arbitrary reference frame, for all stations included in the survey, including the IRM associated with SGT MKEA and the targets intended for use in determination of the CRP associated with SGT 7617. A statistical summary from the adjustment is included in Table 4.

```
                         Adjustment Statistical Summary
                          ==============================
                         Iterations              =      2
                         Number of Stations      =     95
                         Number of Observations  =   1279
                         Number of Unknowns      =    388
                         Number of Redundant Obs =    891

             Observation   Count   Sum Squares         Error
                                     of StdRes         Factor
             Coordinates       3       0.000           0.000
              Directions     499     147.783           0.652
               Distances     487      12.243           0.190
             Az/Bearings       1       0.000           0.000
                 Zeniths     281     345.318           1.328
              Level Data       8      17.598           1.777

                   Total    1279     522.944           0.766
```

Table 4 – Terrestrial survey classical 3-dimensional adjustment statistical summary.

For additional details concerning the classical adjustment of the terrestrial survey, see Star*Net output file MKEA.lst.

Least-Squares Estimates of Conventional Reference Points

AXIS was used to produce coordinates and variance-covariance estimates for the CRP associated with SGT 7617. Star*Net output file MKEA.dmp file, containing coordinates and associated variance-covariance estimates for main scheme network marks and 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 associated with SGT 7617. Table 5 contains statistics from the least squares solution. For additional details, see AXIS output file, output.axs, Section 4.2 “SOLUTION STATISTICS”.

LEAST SQUARES SOLUTION		
# OF TARGETS	:	12
# OF IVP ESTIMATES	:	3
# OF COORDINATE-OBSERVATIONS	:	282
# OF UNKNOWNS	:	116
# OF CONDITIONS	:	180
# OF CONSTRAINTS	:	36
# OF ADD. CONSTRAINTS	:	54
# OF CONSTRAINTS TOTAL	:	90
DEGREES OF FREEDOM	:	436
ITERATIONS TO COMPLETE	:	2
MAXIMUM RESIDUAL (METRE)	:	0.00133
VARIANCE (CONDITIONS)	:	0.27463
VARIANCE (CONSTRAINTS)	:	0.00006
VARIANCE (APRIORI)	:	0.00000
VARIANCE FACTOR	:	0.27469
SIGMA	:	0.52411

Table 5 –AXIS least squares adjustment statistical summary.

Final Coordinate Listing

AXIS was used to compute final coordinate estimates, aligned to reference frame ITRF 2008 (2015/07/12), for all main scheme ground network marks, SGT IRMs and SGT CRPs associated with the current NGS survey. See Table 6 for the compiled coordinate listing. Final coordinates for the CRP associated with SGT 7617 and the IRM associated with SGT MKEA are provided in SINEX format in Attachment A and in AXIS output file ngsMKEA1507ga.snx. Final transformed coordinates for the main scheme network marks are provided in section 5. “GEOCENTRIC VCV TRANSFORMATION” in AXIS output file output.axs

SITE	X (m)	Y (m)	Z (m)		SX (m)	SY (m)	SZ (m)
RM01	-5464050.6495	-2495217.8355	2148358.8368	+/-	0.0001	0.0001	0.0001
RM02	-5464040.2979	-2495276.3405	2148303.1582	+/-	0.0001	0.0001	0.0002
RM03	-5464081.8885	-2495247.9789	2148242.8976	+/-	0.0001	0.0001	0.0001
MKEA	-5464105.3331	-2495165.7131	2148291.5354	+/-	0.0004	0.0006	0.0004
7617	-5464075.2020	-2495247.9386	2148297.4452	+/-	0.0004	0.0003	0.0010

Table 6 –Listing of final ITRF 2008 (2015/07/12) coordinate estimates for main scheme marks and SGT CRPs .

NGS program INVERS3D was used to compute local tie vector information for the two SGT instruments co-located at this ITRF site. ITRF 2008 (2015/07/12) coordinates for the CRP associated with SGT 7617 and the IRM associated with SGT MKEA, determined during the current NGS survey and provided in table 6, were used as input. Table 7 includes the output from that 3-dimensional inverse computation.

```
First  Station :  SGT 7617 ITRF 2008  (2015/07/12)
  ----------------
  X =   -5464075.2020 m  LAT =  19 48  4.99244 North
  Y =   -2495247.9386 m  LON = 155 27 19.84930 West
  Z =    2148297.4452 m  EHT =      3762.9949  Meters
Second Station : SGT MKEA ITRF 2008 (2015/07/12)
  ----------------
  X =   -5464105.3331 m  LAT =  19 48  4.88602 North
  Y =   -2495165.7131 m  LON = 155 27 22.84744 West
  Z =    2148291.5354 m  EHT =      3754.6445  Meters

 DX =        -30.1311 m   DN =        -3.2744 m
 DY =         82.2255 m   DE =       -87.3120 m
 DZ =         -5.9098 m   DU =        -8.3510 m
```

Table 7 – Results from an inverse computation from the CRP of SGT 7617 to the IRM of SGT MKEA using ITRF 2008 (2015/07/12) coordinates determined during the current NGS survey.

<u>Local Tie Vector Comparisons: Survey-derived Versus IERS-Reported.</u>

The IERS reports a local tie vector between SGT 7617 and SGT MKEA in file (4.477.tie) provided at the IERS ITRF Product Center web site. Table 8 includes the local tie information provided in file (4.477.tie).

```
Local tie used in the ITRF2000 primary combination

Site            : 40477
Local tie file : 40477.TIE
Release         : 2003  22  5
---------------------------------------------------------------

 40477 MAUNA KEA
 40477S001  40477M001     -30.1321      82.2265      -5.9084
                            0.0024       0.0016       0.0016
```

Table 8 – Local tie vector between the CRP associated with SGT 7617 (40477S001) and the IRM associated with SGT MKEA (40477M001) as taken from file 4.477.tie.

Table 9 is a compilation of tie vector information from SGP stations 7617 and MKEA previously provided in tables 7 and 8 and provides the discrepancy between the local tie determined this survey against the corresponding local tie reported by the IERS.

```
SGT 7617-MKEA – tie vector computed using ITRF 2008 (2015/07/12)
coordinates determined during the current NGS survey.
  DX =       -30.1322  m  DN =  -3.2749 m
  DY =        82.2253  m  DE = -87.3122 m
  DZ =        -5.9099  m  DU =  -8.3500 m
SGT 7617-MKEA – tie vector as reported by ITRF in file(40477.TIE).
                          *discrepancy*
  DX =       -30.1321 m   DX =   0.0001 m
  DY =        82.2265 m   DY =   0.0012 m
  DZ =        -5.9084 m   DZ =   0.0015 m
```

Table 9 – Tie vector information computed from 2015 NGS survey and as reported by the IERS, including discrepancies between the tie vector information computed from current NGS survey and those reported by the IERS.

6. Planning Aspects

The primary contact for information regarding SGT 7619 is NRAO employee Eric Carlow. Eric's contact information is:'

Eric Carlowe
National Radio Astronomy Observatory (NRAO)
Array Operations Center
P.O. Box O
1003 Lopezville Road
Socorro, NM 87801-0387
Phone: (575) 835-7000, Fax: (575) 835-7027
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On site contacts:

National Radio Astronomy Observatory*
Lyman "Bill" Hancock, Station Manager
bhancock@nrao.edu

Anthony "Tony" Sylvester II, Technical Specialist
tsylvest@nrao.edu

Mauna Kea VLBA Station
C/O MKSS Hale Pohaku
177 Makaala St.
Hilo, Hawaii 96743
Ph: (808) 935-6719, Fax: (808) 933-1843

6.1 Recommendations

- A 4wd vehicle is required to drive the last few miles of the only access road leading to the Observatory.

- Major shipping companies, at least UPS, do not deliver to the Observatory. Support equipment should be shipped to a "shipping" center in Hilo or Kona and "held for pickup" for the survey team.

- The weather and the sun can be extreme at the Observatory, even in the middle of summer, plan accordingly.

- Mauna Kea is considered a cultural and environmentally sensitive area. The survey team will need to conduct field measurements in a manner having minimal impact on the local environment. If new round control marks are required, approval from the office of Mauna Kea Management will be required. The point of contact to pursue approval is:
  Stephanie Nagata, Director
  nagatas@hawaii.edu

  Office of Mauna Kea Management
  640 N. Aohoku Place, Room 203
  Hilo, Hawaii 96720
  Phone: 808.933.0734
  Fax: 808.933.3208

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
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Woodford, VA 22580
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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 A:

```
%=SNX 1.00 AUS 15:278:45768 AUS 15:193:00000 15:194:00000 C 00006 2 X
+FILE/REFERENCE
 DESCRIPTION        Terrestrial Survey Tie
 OUTPUT             SSC SINEX
 CONTACT            ________________________________________________
 SOFTWARE           axis version 1.07
 HARDWARE           ________________________________________________
 INPUT              Terrestrial Survey Solution
-FILE/REFERENCE
+FILE/COMMENT
* axis software by John Dawson Geoscience Australia
-FILE/COMMENT
+SITE/ID
 MKEA  A 40477M001 C GNSS antenna reference -155 27 22.8  19 48  4.9  3754.6
 7617  A 40477S001 C 2m VLBA CRP (SGP 7617) -155 27 19.8  19 48  5.0  3763.0
-SITE/ID
+SITE/DATA
 MKEA  A    1 MKEA  A    1 15:193:00000 15:194:00000 --- 15:193:43200
 7617  A    1 7617  A    1 15:193:00000 15:194:00000 --- 15:193:43200
-SITE/DATA
+SOLUTION/EPOCHS
 MKEA  A    1 C 15:193:00000 15:194:00000 15:193:43200
 7617  A    1 C 15:193:00000 15:194:00000 15:193:43200
-SOLUTION/EPOCHS
+SOLUTION/STATISTICS
 VARIANCE FACTOR               2.746862884459527e-01
 SQUARE SUM OF RESIDUALS       1.197632217624354e+02
 NUMBER OF OBSERVATIONS                          442
 NUMBER OF UNKNOWNS                                6
-SOLUTION/STATISTICS
+SOLUTION/ESTIMATE
     1 STAX   MKEA  A    1 15:193:43200 m    2 -5.46410533312424e+06 3.61829e-04
     2 STAY   MKEA  A    1 15:193:43200 m    2 -2.49516571306328e+06 6.45635e-04
     3 STAZ   MKEA  A    1 15:193:43200 m    2  2.14829153536625e+06 4.43677e-04
     4 STAX   7617  A    1 15:193:43200 m    2 -5.46407520197823e+06 4.43235e-04
     5 STAY   7617  A    1 15:193:43200 m    2 -2.49524793859844e+06 3.23824e-04
     6 STAZ   7617  A    1 15:193:43200 m    2  2.14829744518696e+06 9.83698e-04
-SOLUTION/ESTIMATE
+SOLUTION/MATRIX_ESTIMATE U COVA
     1     1  1.30920320572458e-07 -1.85514402748937e-07  7.46784553065973e-08
     1     4  0.00000000000000e+00  0.00000000000000e+00  0.00000000000000e+00
     2     2  4.16844558534816e-07 -7.05731633892225e-09  0.00000000000000e+00
     2     5  0.00000000000000e+00  0.00000000000000e+00
     3     3  1.96849184543688e-07  0.00000000000000e+00  0.00000000000000e+00
     3     6  0.00000000000000e+00
     4     4  1.96457051043040e-07  5.63178683199491e-08  3.16988145282801e-07
     5     5  1.04862189292247e-07  1.41439940324635e-07
     6     6  9.67661189366329e-07
-SOLUTION/MATRIX_ESTIMATE U COVA
%ENDSNX
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