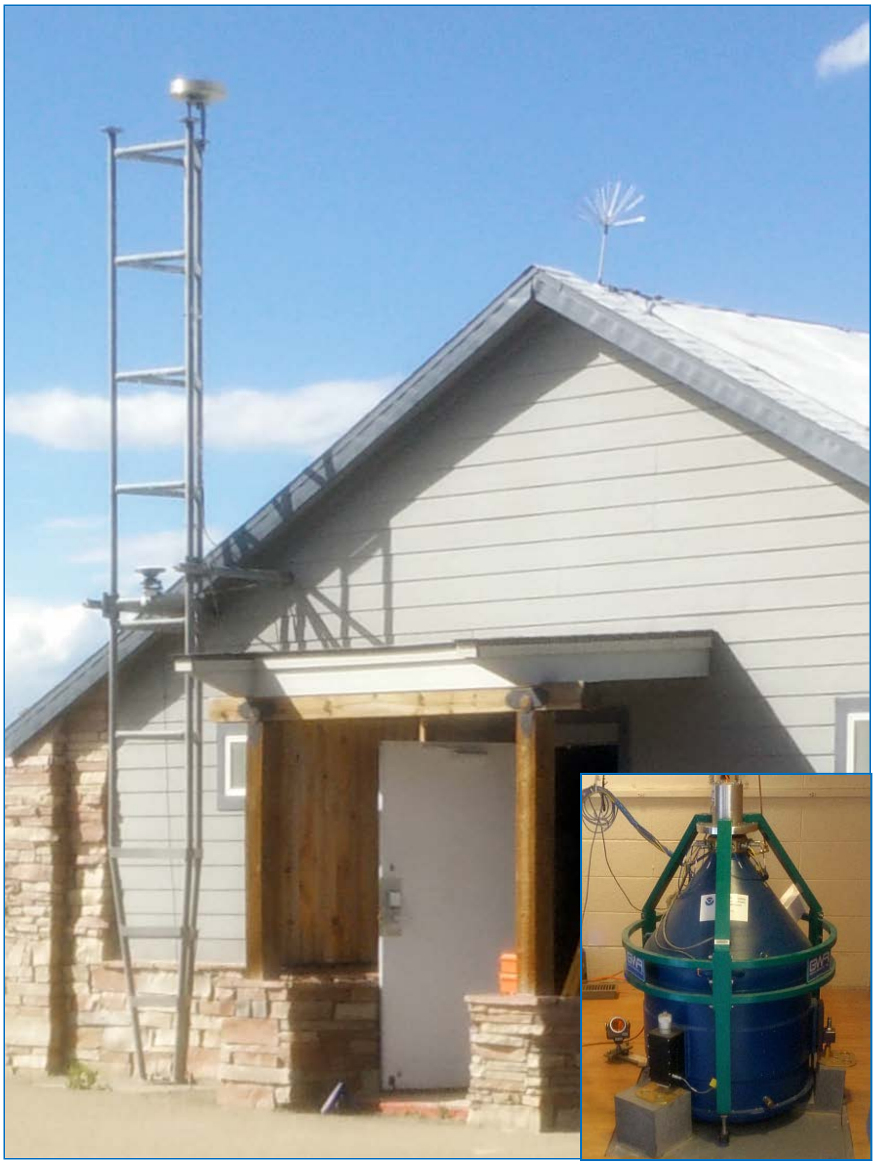
UNITED STATES DEPARTMENT OF COMMERCE
NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE
NATIONAL GEODETIC SURVEY

INTERNATIONAL EARTH ROTATION & REFERENCE SYSTEM SERVICES TABLE MOUNTAIN GRAVITY OBSERVATORY LOCAL SITE SURVEY REPORT



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Dates of Data Collection: June, 2015
Date of Report: June, 2016

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Introduction

During June, 2015, the National Geodetic Survey conducted a high precision local site survey at NOAA's Table Mountain Gravity Observatory near Longmont, Colorado (USA). Data collection consisted of leveling using a digital barcode leveling system, traverse procedures using a high precision tacheometer and static Global Positioning System (GPS) observations using survey-grade duel frequency instrumentation. The objective of the survey was to establish high precision local ties, referenced to the International Terrestrial Reference Frame (ITRF2008), for the reference points associated with a superconducting gravimeter, a Global Navigation Satellite System (GNSS) antenna and existent ground control marks. This report documents the instrumentation and methodologies used to collect the geometric data set and the data reduction and analysis procedures used to compute the local tie vectors.

1. Site Description

Site Name: Table Mountain Gravity Observatory (Colorado)
Country Name: UNITED STATES OF AMERICA
Longitude: 254°46'
Latitude: 40°07'
Tectonic plate: NOAM

Instrument	Name	DOMES#	Description/a.k.a.
GNSS	TMGO	49433M001	Forced centering antenna mount atop a steel tower
GNSS	TARP		Threaded hole in antenna bottom of pre-amp (BPA)
Superconducting Gravimeter	AKSG		Brass mark set in floor
Superconducting Gravimeter	SCCH		Top center of gravimeter cold head

Table 1 –Primary instruments and marks located at the site.

2. Instrumentation

2.1. Tacheometers

2.1.1. Description

Leica TDM5005
S/N: 441698
<u>Specifications</u>
Angular measurement uncertainty: ± 0.7"
Distance standard deviation of a single measurement: 1 mm + 2 ppm
Distance offset selected for project, +34.4 mm

2.1.2. Calibrations

The tacheometer was originally calibrated by Leica Geosystem AG Heerbrugg, Switzerland.
Inspection date: 08/20/2008

2.1.3. Auxiliary Equipment

Wild NL Collimator, S/N: 279330, Pointing accuracy, 1: 200,000
Hygrometer: Omega RH83
Thermometer: DORIC 450, S/N 00662, with thermistor sensor fabricated by NGS

2.2. GPS Units

2.2.1. Receivers

Trimble NetR5
P/N: 62800-00
S/Ns: 4619K01307, 4624K01648, and 4624K01584 and 462K01631
<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 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 3-m Invar Bar Code Rod
S/Ns: 30579, 27226, 27227

2.3.3. Checks carried out before measurements

Prior to observations the instrument's reticle was to checked to ensure it was coincident with the instrument's horizontal line of sight. 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

Standard wooden surveying tripods, with collapsible legs, were used to support surveying instrumentation centered over all ground network marks.

2.5. Forced Centering Devices

At each tripod setup, a Leica GDF321 tribrach was plumbed precisely over a survey mark disk using a Wild NL Collimator. The tribrach was "leveled up" using a Leica Geosystems 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. On marks that were not occupied, trivets were used to center fixed height pins, with retro-reflectors attached, over marks.

To facilitate precise measurement of the height of instruments/reflectors above each mark, a tribrach adapter was locked into the tribrach, the top of same serving as a vertical point of reference. Digital leveling equipment was used to transfer a height difference from the survey mark 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 was previously determined by NGS and represents the distance from the tribrach adapter's vertical point of reference to either the center of the tilt axis of the tacheometer's telescope or the center of a target/reflector.

2.6. Targets, Reflectors

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

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

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.

3. Measurement Setup

3.1. Ground Network

Ground network marks are monumented for future reference. The terrestrial survey ties them 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. Ground network marks are used to tie GNSS and gravimetric instruments, as well as a number of gravity marks, to the network, and indirectly, to each other.

Three temporary stations were part of the ground network. SCNO, SCSO and SDOR were not monumented.

3.1.1. Listing

Current Survey	DOMES	IERS 4-char code	Current Survey id	Previous Survey Point Name	NGS PID
Ground Network Marks					
A TMGO	n/a	n/a	ATMG	-no previous site survey-	AE5128
BOULDER CG	n/a	n/a	BOCG	-no previous site survey-	DE5954
ECKL	n/a	n/a	ECKL	-no previous site survey-	n/a
TMGO RM 1	n/a	n/a	TMR1	-no previous site survey-	n/a
TMGO RM 2	n/a	n/a	TRM2	-no previous site survey-	n/a
WELL HEAD	n/a	n/a	WELL	-no previous site survey-	n/a
Technique Instrument Reference Mark					
TABLE MOUNTAIN CORS MON	40456M001	TMGO	TMGO	-no previous site survey-	n/a
BOULDER AK	n/a	n/a	BOAK	-no previous site survey-	DE5945
Technique Conventional Reference Points					
TABLE MOUNTAIN CORS ARP	n/a	n/a	TARP	-no previous site survey-	AF9516
SG COLD HEAD	n/a	n/a	SGCH	-no previous site survey-	n/a

Table 2 – Listing of Ground Network Marks, Instrument Reference Marks and Conventional Reference Points.

Ground Network Marks

A TMGO (ATMG)

The station is a forced-centering pier with a 5/8-11 threaded stud projecting from a metal plate stamped---A TMGO 1995--- atop a 50 cm (18”) in diameter concrete pier encased in a PVC pipe projecting 1.5 m (60”) above the ground, located inside four wooden posts 62.5 m (205’) NE of the NE end of Bldg. F-6. This mark is designated as the geometric reference point (GRP) for the site.

Figure 1 – A TMGO: site survey GRP

BOULDER CG (BOCG)

The station is a NGS gravity disk stamped---BOULDER CG 1993---, set in a square concrete pad, 1.5 m (5’) on side and flush with the ground, located on the easterly side of the TMGO office building, 8.5 m (28’) SSE of the ENE corner and 9 m (30’) NE of the SSE corner.

Figure 2 – Ground network mark BOULDER CG

ECKL (ECKL)

The station is a NGS gravity disk stamped---ECKL 2014---, set in the top of a concrete post flush with the ground, located 9 m (30') NW of the center of the driveway to the TMGO parking lot, 9.3 m (30.5') SW of the SW corner of the parking lot and 2.4 m (8') west of the SW corner of a concrete pad, 3 m X 7 m (10' X 24')

Figure 3 – Ground network mark ECKL

TMGO RM 1 (TMR1)

The station is a NGS reference mark disk stamped---TMGO NO 1 2014---, set in the top of a concrete post flush with the ground, located 17 m (55') WNW of the N corner of the TMGO parking lot, 28 m (93') NW of the north corner of Bldg. F-6, and 1.7 m (5.5') SSW of a drainage ditch.

Figure 4 – Ground network mark TMGO RM 1

TMGO RM 2 (TMR2)

The station is a NGS reference mark disk stamped---TMGO NO 2 2014---, set in the top of a concrete post flush with the ground, located near a propane tank on the SE side of Bldg. F-6, 3.5 m (12') east of the center of the tank, 10 m (33') SE of the east corner of the building and 14 m (47') ENE of the south corner of the building.

Figure 5 – Ground network mark TMGO RM 2

WELL HEAD (WELL)

The station is a NGS survey disk stamped---N E S W---, set in a 1.7 m X 3.4 m (5' X 11') concrete pad between two well heads, located near a wooden shed at the east corner of the TMGO parking lot, 3.7 m (12') NW of the parking lot corner, 5.5 m (18') west of the north corner the shed and 11 m (36') NE of the NE entrance to Bldg. F-6.

Figure 6 – Ground network mark WELL HEAD

Instrument Reference Marks

TABLE MTN CORS MON (TMGO)
The station is a forced-centering antenna mount atop a 6 m (20’) steel tower with bracing about halfway up the tower anchoring it to Bldg. F-6. A 5/8-11 stud protrudes through a 15 cm (6”) diameter steel plate. The mark was positioned by intersection. Elevation was determined by trigonometric leveling.

Figure 7 – TABLE MOUNTAIN CORS MON

BOULDER AK (BOAK)
The station is a NGS gravity disk stamped---BOULDER AK 1993---, set in the top center of a rectangular concrete post 85 cm X 100 cm (34” X 40”) flush with the floor inside the superconducting gravimeter (SG) enclosure inside Bldg. F-6. Currently, the SC gravimeter is resting squarely over the mark. A special circle offset bar was designed to allow indirect measurement for 3-D positioning and orthometric height determination.

Conventional Reference Points

TABLE MTN CORS ARP (TARP)
The antenna reference point is the center of the “bottom of the pre-amp” (BPA), the 5/8-11 threaded hole in the bottom of the antenna used for mounting. The ARP was positioned by intersection. Elevation was determined by trigonometric leveling.

Figure 8 – TABLE MOUNTAIN CORS ARP

SG COLD HEAD (SGCH)
The CRP is the top center of the cylindrical cold head mounted atop the superconducting gravimeter. The point was positioned by intersection. Elevation was determined by differential leveling

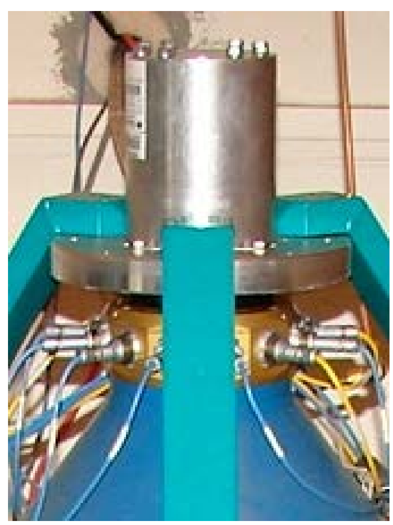

Figure 9 - SG COLD HEAD

3.1.2. Map of Network

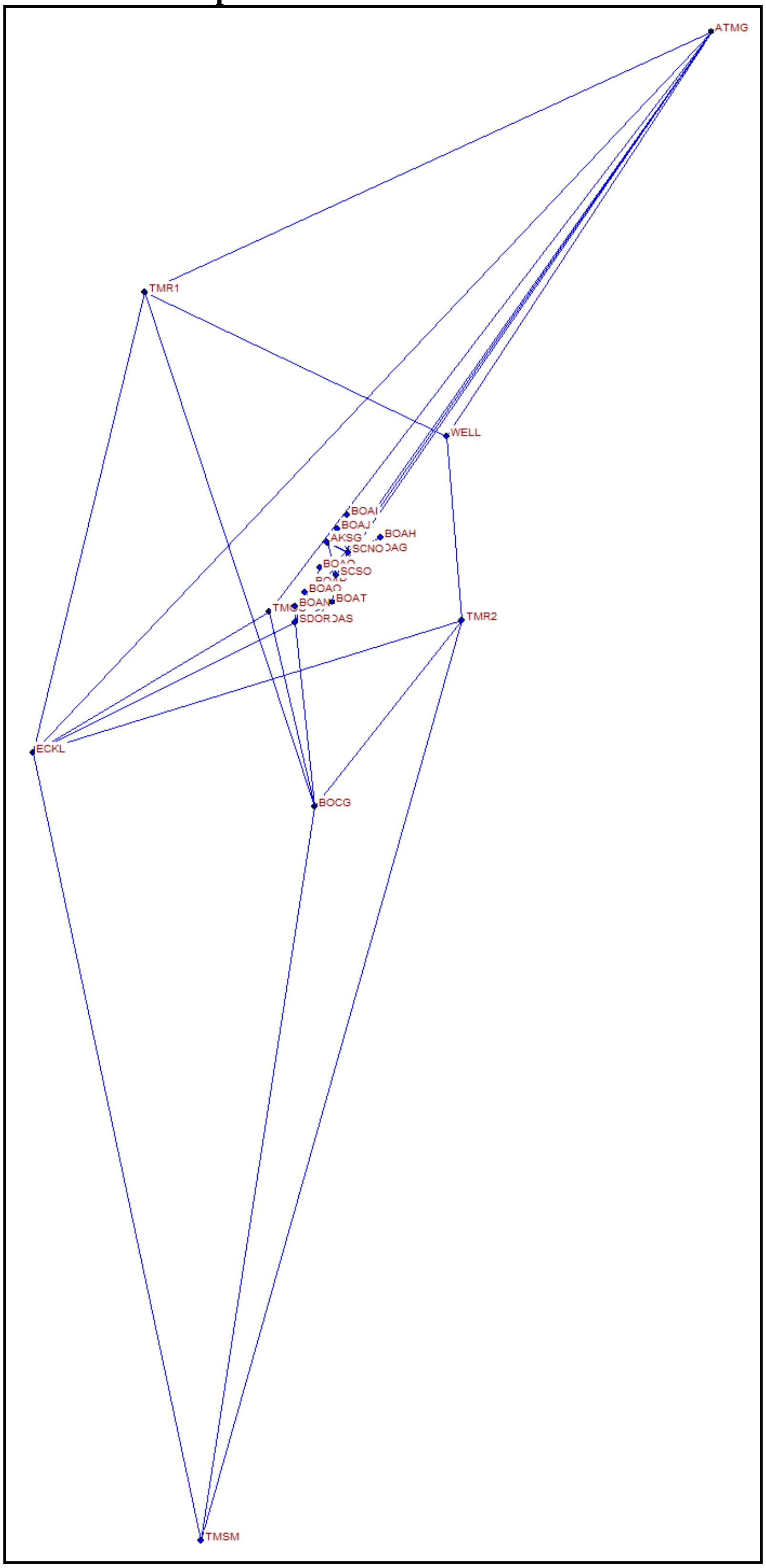

Figure 4 - Observing scheme

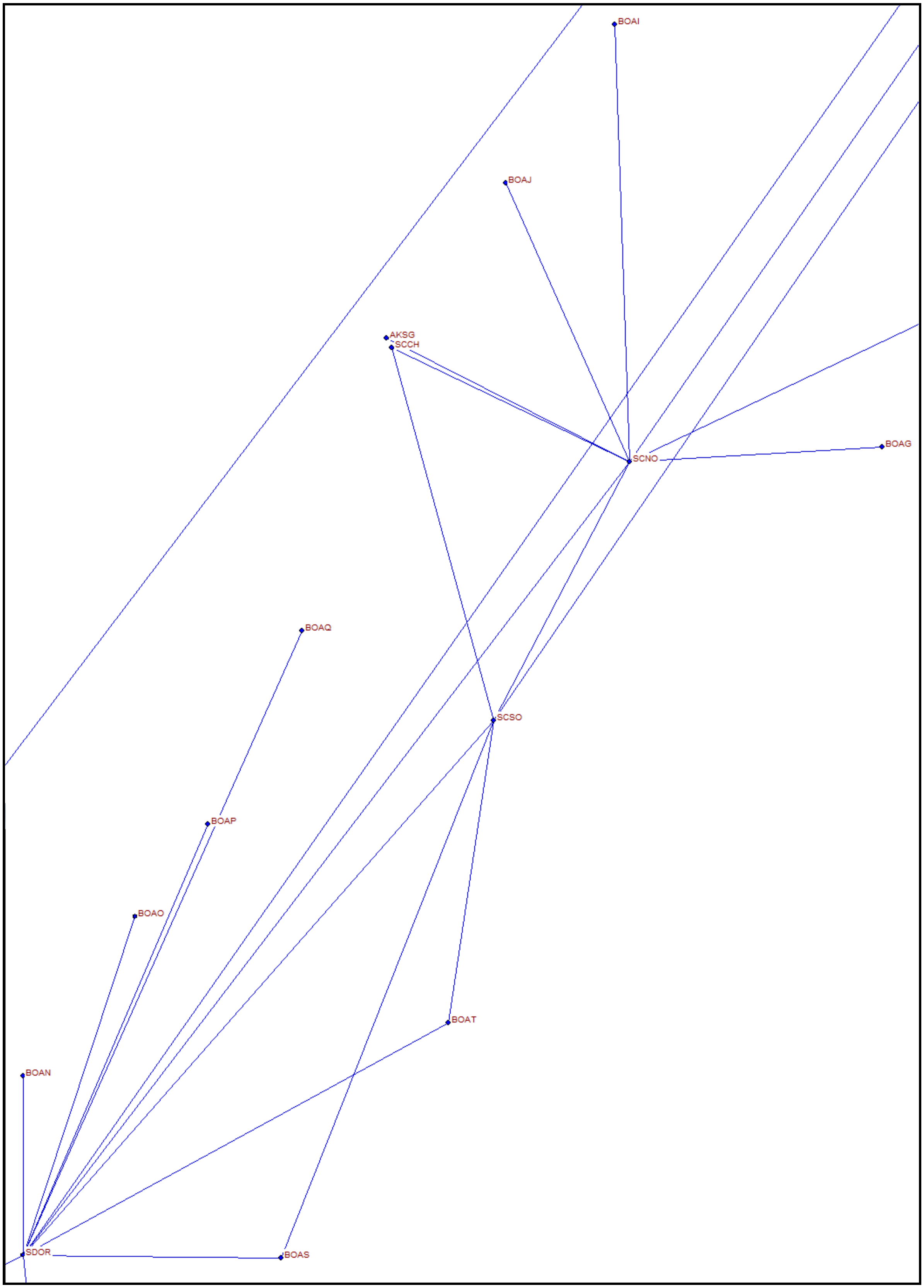

Figure 5 – Detail of observing scheme from Figure 4. These are gravity marks inside Bldg. F-6

3.2. Representation of Technique Reference Points

3.2.1 GPS

TMGO - NOAA's National National Geodetic Survey operates the continuously operation reference station (CORS). The station is included in the U.S. national CORS network. The antenna type at time of this survey was an Ashtech IGS antenna code ASH700936E (no radome), S/N: CR16199. The Antenna Reference Point (ARP) was reported by the NGS to be coincident with the IRM, no offsets. Without removal of the antenna, the IRM cannot be fitted with surveying equipment for a direct tie to the ground network. Coordinates for the IRM and CRP were determined by intersection method from ground network marks A TMGO, ECKL, and TMGO RM 2. A site log for TMGO is available at the NGS web page ftp://geodesy.noaa.gov/cors/station_log/tmgo.log.txt

Figure 6 – NGS CORS TMGO

3.2.2 Gravity Meter

Superconducting Gravimeter (SG) - NOAA's National National Geodetic Survey operates the SG relative to gravity mark BOULDER AK, the IRM. Neither the CRP nor the IRM could be fitted with surveying equipment that would allow a direct tie to the ground network. The CRP was intersected from temporary ground network marks SCNO and SCSO. A differential leveling tie was made directly to the CRP. A custom-made circle offset bar was used to determine a 3-D position and elevation.

Local tie vector from BOULDER AK (IRM) to SG COLD HEAD (CRP):

```
DN =        -0.0884 m
DE =         0.0449 m
DU =         1.2896 m
```

Figure 7 – NGS SC gravimeter set up over IRM. The circle offset bar with prism can be seen to the left of the SG.

4. Observations

4.1. Conventional Survey

The conventional survey consisted of measuring horizontal/vertical angles and distances using a high precision tacheometer, employing traverse procedures between and/or to all features of interest. All angular and distance measurements were observed a minimum of three repetitions and incorporated double centering of the tacheometer, otherwise known as measuring in both phase I and phase II. For distance measurements, meteorological data were input into the tacheometer and refractive index corrections were applied internally 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 TMGO.lst.

4.2. Leveling

Leveling data was collected for the purpose of determining high precision height difference information referenced to the geoid. Leveling between all ground control network mark, gravity marks and gravimeter CRP SG COLD HEAD were performed to Federal Geodetic Control Sub-committee (FGCS) First Order, Class I standards.

The initial double-run loop began at ECKL, then to BOULDER CG, then to TMGO RM 2, then to WELL HEAD, then spur in A TMGO, then to TMGO RM 1, closing back on ECKL. The next series of leveling sections essentially cut the first loop in half. Beginning at WELL HEAD, then to BOULDER AH, then to BOULDER AG, then to BOULDER AI, then to BOULDER AJ, then spur in SC COLD HEAD, then to BOULDER AQ, then to BOULDER AP, then to BOULDER AO, then to BOULDER AN, then to BOULDER AT, then to BOULDER AS, then tying back into TMGO RM 2.

The measured height differences between marks were incorporated into a classical 3-dimensional adjustment of the terrestrial data. A complete listing of unadjusted leveling observations is available in TMGO15.abs.

4.3. GPS

GPS data was collected for the purpose of determining high-precision, 3-dimensional IGS08(epoch date of survey 2015/06/03, aka eds) coordinates for ground network marks marks (A TMGO, ECKL, TMGO RM 1 and BOULDER CG). GPS data collection consisted of simultaneous and long-session observations conducted over multiple days. GPS derived coordinates for the four marks was used to align or transform the local terrestrial network to ITRF2008(eds).

4.4. General Comments

As noted earlier, determining the local coordinates of the IRM BOULDER AK 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 the circle offset bar as it moves about the mark, thereby providing the necessary information to locate a single axis.

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-D adjustment of the terrestrial data. Measurements included in the adjustment consisted of terrestrial observations of all ground network marks and intermediate target points on the circle offset bar. The adjustment produced geodetic coordinates and variance-covariance information for all features surveyed. The adjustment included height differences between ground network marks determined by differential leveling and included the CRP SG COLD HEAD. Terrestrial adjustment parameters and results can be found in Star*Net output file TMGO.lst. Terrestrial adjustment variance-covariance estimates can be found in the Star*Net output file TMGO.dmp.

AXIS 1.07 software, developed by Geoscience Australia (GA), was used to perform 3-dimensional arc fitting to compute an axis in space, which in turn was used to estimate the IRM associated with the gravimetric instrument SG COLD HEAD. A Star*Net output file (TMGO.dmp) containing coordinate and variance-covariance estimates for intermediate targets affixed to the circle offset bar was converted to VCV format file (TMGO.vcv) using NGS software HALF2VCV, which was then used as initial input. Circle fitting constraints can be found in AXIS input file setup.axs.

5.1.2. Topocentric Coordinates and Covariance

Topocentric coordinates and covariance information, from the classical adjustment of the terrestrial data, for ground network marks, VLBA targets 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 ground network marks, the CRP associated with SGT 7234 can be found in section 6. "SINEX GENERATION" in AXIS output

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-ITRF.snx".

5.3. Additional Parameters

5.3.1. Gravity Meter CRP Offset from Instrument Mark Computation

NGS Program INVERS3D was used to compute offset values from BOULDER AK (IRM) to SG COLD HEAD (superconducting gravimeter CRP). Final coordinates for these marks, provided in Table 5, was used as input. Offset values were computed to be delta north -0.0884 m, delta east +0.0449 m and delta up +1.2896 m. The International Gravity Field Service (IGFS) reports these offset values to be a little on the heavy side but thanked NGS all the same for weighing in on the issue.

5.3.2. GPS Antenna Reference Point Offset from Instrument Mark Computation

Zero offsets. CRP and IRM are coincident.

5.4. Transformation

Local tie vectors from the terrestrial survey were accurately aligned, or transformed, from a geodetic frame to ITRF2008(eds) 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. A TMGO, ECKL, TMGO RM 1 and BOULDER CG were used in the current survey. The spatial integrity of the terrestrial survey is maintained throughout the transformation process. Transformation parameters and results can be found in section 5. "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 file 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 ***NGSTMGO1506GA.snx*** is found in Attachment 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 geodetic reference frame, for all stations included in the survey and the targets intended for use in determination of IRM BOULDER AK. A statistical summary from the adjustment is included in Table 3.

```
                Adjustment Statistical Summary
                ==============================
               Iterations              =      5
               Number of Stations      =     31
               Number of Observations  =    494
               Number of Unknowns      =    124
               Number of Redundant Obs =    370

   Observation   Count   Sum Squares         Error
                           of StdRes         Factor
   Coordinates       9        0.001          0.014
        Angles      33        9.630          0.624
    Directions     144       10.803          0.316
     Distances     144        8.867          0.287
       Zeniths     126      315.493          1.828
    Level Data      38       50.934          1.338
   ----------------------------------------------------
         Total     494      395.729          1.034

         The Chi-Square Test at 5.00% Level Passed
              Lower/Upper Bounds (0.928/1.072)
```

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

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

AXIS was used to produce coordinates and variance-covariance estimates for the IRM associated with SG COLD HEAD. A VCV file, containing coordinates and associated variance-covariance estimates for main scheme network marks and targets affixed to the circle offset bar, was used as input. The VCV file (TMGO.vcv) was created from Star*Net output file TMGO.dmp using NGS program HALF2VCV. AXIS performed 3-dimensional arc fitting to compute multiple axes in space, which in was turn used to estimate the IRM associated with SG COLD HEAD. Table 4 contains statistics from the least squares solution. For additional details, see AXIS output file, output.axs, Section 3.2 “SOLUTION STATISTICS”.

LEAST SQUARES SOLUTION		
# OF TARGETS	:	1
# OF IVP ESTIMATES	:	0
# OF COORDINATE-OBSERVATIONS	:	45
# OF UNKNOWNS	:	7
# OF CONDITIONS	:	14
# OF CONSTRAINTS	:	1
# OF ADD. CONSTRAINTS	:	0
# OF CONSTRAINTS TOTAL	:	1
DEGREES OF FREEDOM	:	53
ITERATIONS TO COMPLETE	:	2
MAXIMUM RESIDUAL (METRE)	:	0.00075
VARIANCE (CONDITIONS)	:	0.03910
VARIANCE (CONSTRAINTS)	:	0.00000
VARIANCE (APRIORI)	:	0.00000
VARIANCE FACTOR	:	0.03910
SIGMA	:	0.19773

Table 4 –Statistical summary from least squares adjustment of circle offset targets on IRM BOULDER AK

Final Coordinate Listing

AXIS was used to compute final coordinate estimates, aligned to reference frame ITRF2008 (eds), for all ground network marks, the IRM and ARP associated with TMGO and SG COLD HEAD associated with the current NGS survey. See Table 5 for the compiled coordinate listing. Final coordinates for the CRP associated with TMGO and the IRM for SG COLD HEAD are in SINEX format in the Attachment and in AXIS output file NGSTMGO1506GA.snx.

CARTESIAN COORDINATES - EARTH CENTRE ORIGIN (METRES) - VARIANCE-COVARIANCE

SITE	X	Y	Z	SX	SY	SZ
A TMGO	-1283330.6496	-4712984.4810	4090234.0045	0.0000	0.0000	0.0000
BOULDER AG	-1283375.0417	-4713009.6312	4090191.1933	0.0001	0.0001	0.0001
BOULDER AH	-1283373.7716	-4713008.9722	4090192.3396	0.0001	0.0001	0.0001
BOULDER AI	-1283376.8068	-4713006.5005	4090194.2362	0.0001	0.0001	0.0001
BOULDER AJ	-1283378.0497	-4713007.1581	4090193.0877	0.0001	0.0001	0.0001
BOULDER AK	-1283379.3706	-4713007.7706	4090191.9636	0.0002	0.0002	0.0001
BOULDER AN	-1283383.8443	-4713011.2256	4090186.6627	0.0001	0.0001	0.0001
BOULDER AO	-1283382.5737	-4713010.5647	4090187.8139	0.0001	0.0001	0.0001
BOULDER AP	-1283381.7683	-4713010.2029	4090188.4802	0.0001	0.0001	0.0001
BOULDER AQ	-1283380.6054	-4713009.2987	4090189.8731	0.0001	0.0001	0.0001
BOULDER AS	-1283381.7797	-4713012.9251	4090185.3560	0.0001	0.0001	0.0001
BOULDER AT	-1283379.8896	-4713011.9534	4090187.0529	0.0001	0.0001	0.0001
BOULDER CG	-1283385.3012	-4713024.9645	4090170.1362	0.0000	0.0000	0.0000
ECKL	-1283413.4940	-4713013.7115	4090174.5816	0.0000	0.0000	0.0000
SG COLD HEAD	-1283379.6013	-4713008.7887	4090192.7272	0.0001	0.0001	0.0001
TABLE MTN CORS ARP	-1283387.9060	-4713015.4540	4090190.2830	0.0000	0.0000	0.0000
TABLE MTN CORS MON	-1283387.9060	-4713015.4540	4090190.2830	0.0000	0.0000	0.0000
TMGO RM 1	-1283393.6264	-4712985.7056	4090212.1669	0.0000	0.0000	0.0000
TMGO RM 2	-1283366.7601	-4713016.4530	4090185.3132	0.0001	0.0001	0.0001
WELL HEAD	-1283365.0314	-4713003.7376	4090200.3276	0.0001	0.0001	0.0001

Table 5 –Listing of final ITRF2008(eds) coordinate estimates for ground network marks, CRPs and IRMs

Table 6 provides the local tie vectors, determined during this survey, emanating from the geometric reference point (GRP) A TMGO to TABLE MTN CORS ARP, TABLE MTN CORS MON, BOULDER AK and SG COLD HEAD. NGS program INVERSE3D was used to compute the tie vector information.

```
From  Station : A TMGO (GRP)
----------------
X =   -1283330.6496 m  LAT =  40  7 53.38697 North
Y =   -4712984.4810 m  LON = 105 13 55.77635 West
Z =    4090234.0045 m  EHT =      1666.8157  Meters

       To Station : BOULDER AK (SG IRM)
       ----------------
         X =   -1283379.3706 m  LAT =  40  7 51.60822 North
         Y =   -4713007.7706 m  LON = 105 13 57.50305 West
         Z =    4090191.9636 m  EHT =      1666.6866  Meters

         DX =       -48.7210 m   DN =       -54.8774 m
         DY =       -23.2896 m   DE =       -40.8905 m
         DZ =       -42.0409 m   DU =        -0.1295 m

       To Station : SG COLD HEAD (SG CRP)
       ----------------
         X =   -1283379.6013 m  LAT =  40  7 51.60536 North
         Y =   -4713008.7887 m  LON = 105 13 57.50115 West
         Z =    4090192.7272 m  EHT =      1667.9762  Meters

         DX =       -48.9517 m   DN =       -54.9658 m
         DY =       -24.3077 m   DE =       -40.8456 m
         DZ =       -41.2773 m   DU =         1.1601 m

       To Station : TABLE MTN CORS MON  (CORS IRM)
       ----------------
         X =   -1283387.9060 m  LAT =  40  7 51.36485 North
         Y =   -4713015.4540 m  LON = 105 13 57.76556 West
         Z =    4090190.2830 m  EHT =      1672.9862  Meters

         DX =       -57.2564 m   DN =       -62.3860 m
         DY =       -30.9730 m   DE =       -47.1074 m
         DZ =       -43.7215 m   DU =         6.1700 m

     To Station : TABLE MTN CORS ARP  (CORS CRP)
       ----------------
         X =   -1283387.9060 m  LAT =  40  7 51.36485 North
         Y =   -4713015.4540 m  LON = 105 13 57.76556 West
         Z =    4090190.2830 m  EHT =      1672.9862  Meters

         DX =       -57.2564 m   DN =       -62.3860 m
         DY =       -30.9730 m   DE =       -47.1074 m
         DZ =       -43.7215 m   DU =         6.1700 m
```

Table 6 – Includes local tie vectors emanating from geometric reference point (GRP) A TMGO.

6. Planning Aspects

Contact information

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Government Cell Phone: 240-988-6341

Recommendations:
Watch out for snakes on sunny warm days. There are bunnies in the vicinity of the Table Mountain Gravity Observatory.

7. References

7.1. Name of person(s) responsible for observations

Kendall Fancher (Kendall.Fancher@noaa.gov)
Charles Geoghegan (Charles.Geoghegan@noaa.gov)

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7.2. Name of person(s) responsible for analysis

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Charles Geoghegan (Charles.Geoghegan@noaa.gov)

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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

Attachment: SINEX Format

```
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+FILE/REFERENCE
 DESCRIPTION        Table Mountain Gravity Observatory Terrestrial Survey Tie
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 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
 ATMG  A --------- C A TMGO                -105 13 55.8  40  7 53.4  1666.8
 BOAK  A --------- C BOULDER AK            -105 13 57.5  40  7 51.6  1666.7
 SGCH  A --------- C SG COLD HEAD          -105 13 57.5  40  7 51.6  1668.0
 TARP  A --------- C TABLE MTN CORS ARP    -105 13 57.8  40  7 51.4  1673.0
 TMGO  A --------- C TABLE MTN CORS MON    -105 13 57.8  40  7 51.4  1673.0
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+SITE/DATA
 ATMG  A    1 ATMG  A    1 15:154:00000 15:155:00000 --- 15:154:43200
 BOAK  A    1 BOAK  A    1 15:154:00000 15:155:00000 --- 15:154:43200
 SGCH  A    1 SGCH  A    1 15:154:00000 15:155:00000 --- 15:154:43200
 TARP  A    1 TARP  A    1 15:154:00000 15:155:00000 --- 15:154:43200
 TMGO  A    1 TMGO  A    1 15:154:00000 15:155:00000 --- 15:154:43200
-SITE/DATA
+SOLUTION/EPOCHS
 ATMG  A    1 C 15:154:00000 15:155:00000 15:154:43200
 BOAK  A    1 C 15:154:00000 15:155:00000 15:154:43200
 SGCH  A    1 C 15:154:00000 15:155:00000 15:154:43200
 TARP  A    1 C 15:154:00000 15:155:00000 15:154:43200
 TMGO  A    1 C 15:154:00000 15:155:00000 15:154:43200
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+SOLUTION/STATISTICS
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 NUMBER OF OBSERVATIONS                          68
 NUMBER OF UNKNOWNS                              15
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+SOLUTION/ESTIMATE
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     3 STAZ   ATMG  A    1 15:154:43200 m    2  4.09023400454453e+06 1.22949e-04
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     5 STAY   BOAK  A    1 15:154:43200 m    2 -4.71300777060618e+06 1.01726e-03
     6 STAZ   BOAK  A    1 15:154:43200 m    2  4.09019196361377e+06 8.68120e-04
     7 STAX   SGCH  A    1 15:154:43200 m    2 -1.28337960128931e+06 7.84441e-04
     8 STAY   SGCH  A    1 15:154:43200 m    2 -4.71300878869747e+06 7.81892e-04
     9 STAZ   SGCH  A    1 15:154:43200 m    2  4.09019272724464e+06 7.52609e-04
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    12 STAZ   TARP  A    1 15:154:43200 m    2  4.09019028304723e+06 1.73084e-04
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```

```
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     1    13  9.47268622953404e-09  4.53455939165866e-09  8.53970296555618e-09
     2     2  1.01977652448417e-08  1.07836874916260e-08  5.98086559952585e-09
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