TRIMBLE CHOKE RING ANTENNA MEAN PHASE CENTER CALIBRATION

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Abstract

The consistency of the phase center offsets of GPS antennas is important when trying to achieve geodetic measurements which are accurate at the millimeter level. UNAVCO has previously tested the NASA-UNAVCO pool of Allen Osborne Associates SNR-8000 Turborogue Dorne-Margolin (DM) choke ring antennas manufactured in 1992. These results showed an Ionosphere Free (L3) horizontal baseline scatter of 1.5 mm between antennas of the same model number. The nominal phase center offset for these antennas is zero. Full rotation tests conducted by Trimble in early 1996 on their prototype choke ring antenna using newly built Dorne-Margolin antenna elements showed an L3 systematic horizontal offset of up to 3 mm, significantly larger than previously found and attributable to the particular pair of DM elements used. Random tests of DM antennas subsequently delivered to Trimble showed sub-mm offsets. In order to confirm these results with the first Trimble choke ring antennas delivered to UNAVCO, we conducted full rotation tests using a subset of 11 antennas from the new equipment pool. This testing occurred at the NOAA Table Mountain Gravity Observatory (TMGO) test facility. Using three or more antennas allows for absolute calibration of the horizontal phase center offsets. The results show sub-mm L1 and L2 offsets and L3 offsets of less than 1.8 mm in both horizontal components. The effect of changing the processing elevation cutoff from 20 degrees above the horizon to 10 degrees is less than 10 percent. The relative vertical offset derived from swapping of antennas shows a scatter of less than 1 mm.

Introduction

As an option to the 1995 UNAVCO group Academic Research Infrastructure (ARI) purchase, Trimble Navigation is offering a choke ring antenna with a Dorne-Margolin element. This antenna, called here the TRIM-CHOKE and defined as the DORNE MARGOLIN TRIM by the International GPS Service for Geodynamics (IGS), was designed to match the choke ring antennas used in the IGS network. This type of antenna is also used with the Allen Osborne Rogue and Turborogue receivers as well as the Ashtech Z-XII receiver. The extensive use of this type of antenna in the IGS global network makes it a defacto standard in the community.

It has been shown that mismodeling of antenna phase center variations can cause both horizontal and vertical surveying errors (EOS supplement Vol 76, No 46, November 7, 1995, G22A-6, and UNAVCO ARI Receiver and Antenna Test Report, Chapter 7). The vertical errors can be magnified when estimating individual tropospheric delay parameters in addition to station coordinates. To minimize this problem (especially for local and regional surveys), it is recommended that the same type of antennas be used throughout an experiment. This makes the phase center variations a common mode error that can be removed by observation differencing. When not using antennas of the same make and model, mean offset and elevation phase center variations must be applied to minimize differences between antennas.

Successful application of these antenna phase center variations relies on the assumption that antennas of the same model type behave similarly. Previous tests on a set of seven AOA choke ring antennas were conducted by UNAVCO to determine the antenna consistency within a model type. These results showed that the AOA choke ring antennas have a horizontal variation of approximately 1.5 mm for the L3 phase center. These results were presented at the 1994 Fall AGU (EOS supplement Vol 75, No 44, November 1, 1994, G31B-08), and can be downloaded through UNAVCO's anonymous ftp (ftp.unavco.ucar.edu:pub/ant_phase/agu_94_figs/AGU94.ps).

Full rotation tests conducted by Trimble in early 1996 on their prototype TRIM-CHOKE antennas using recently acquired Dorne-Margolin antenna elements showed an L3 systematic horizontal offset of up to 3 mm, significantly larger than previously found at UNAVCO. When these elements were replaced with older DM elements the offsets were sub-mm suggesting a problem with the newer DM elements. Trimble then went to the Dorne-Margolin Company and although no clear manufacturing problem could be identified, subsequent testing of DM antenna elements delivered to Trimble had sub-mm offsets in tests of phase center variations relative to a model, or ideal antenna.

In order for the UNAVCO facility to obtain a quantitative value of the phase center variability within the equipment pool, a subset of eleven antennas were tested before shipping them to individual UNAVCO member institutions. Before testing the TRIM-CHOKE antennas, in March 1996, UNAVCO tested a pair of choke ring antennas from Allen Osborne and from Ashtech. From these tests (shown in Table 1) it can be seen that variations within a model type may be as large as a few millimeters. The AOA pair, from the older UNAVCO pool, shows offsets of 1 mm or less, comparable to previous UNAVCO results. The Ashtech offsets are larger than 2 mm. Because only two antennas from each manufacturer were used to determine these offsets some caution must be used when applying these variations to a larger number of antennas. Further testing of Ashtech choke ring antennas is needed to confirm these larger offsets.

Table 1: L3 Phase Center Variability For Two Choke Ring Antennas

Antenna Type	North-South	East-West	Height
AOA	1.0mm	0.5mm	0.5mm
ASHTECH	0.05	2.35	0.1

Results from testing of the TRIM-CHOKE antennas show that for a single component, the phase center for individual antennas within the TRIM-CHOKE model can be up to 1.8 mm away from the physical center of the antenna (for the ionosphere free L3 linear combination of L1 and L2 carrier phase frequencies). In addition, it is also shown here that individual horizontal phase centers can be estimated from antenna rotations using a network of three or more stations. The results of baseline scatter for the horizontal L3 components are shown in figures 1 and 2. The scatter without individual phase center offsets (red “+” symbols) and the residual error with the offsets removed (green “*” symbols) are shown in both figures. The high scatter of the solutions without orientation offsets applied (the red “+” symbols) is caused by antenna orientations alternating between North and South. The orientation errors produce a much higher horizontal component scatter than if all antennas were aligned in a common direction. Using this solution scatter and combining it with the antenna orientation information, it is possible to estimate the DC phase center offset for each antenna.

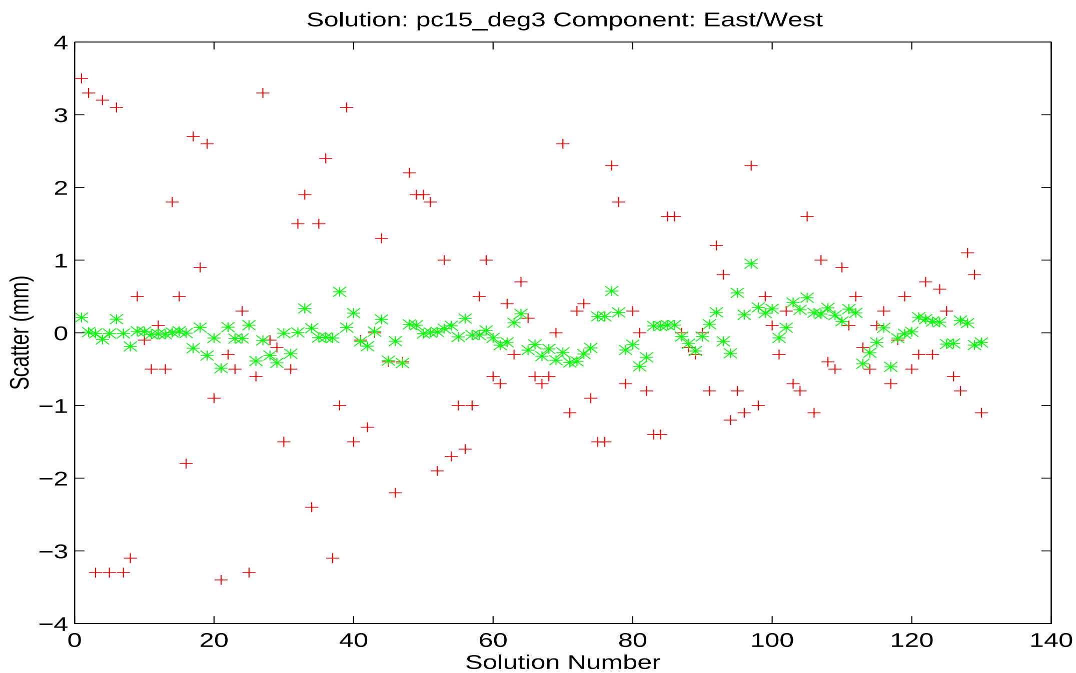

Figure 1: East/West baseline component scatter for antenna calibration tests. Red “+” symbols represent scatter without individual antenna phase offsets applied. Green “” symbols represent scatter of position residuals after estimation of individual phase offsets. Much of the high scatter is attributed to the rotation of antennas.*

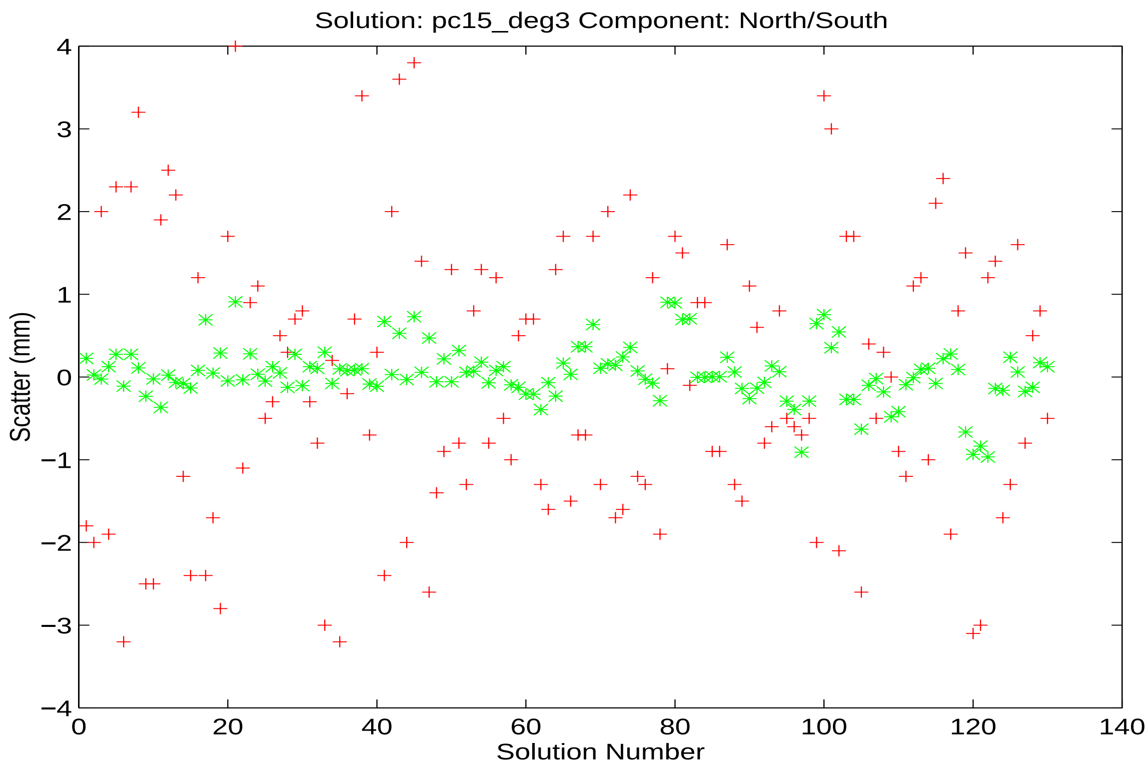

Figure 2:North/South baseline component scatter for antenna calibration tests. Red "+" symbols represent scatter without individual antenna phase offsets applied. Green "" symbols represent scatter of position residuals after estimation of individual phase offsets. Much of the high scatter is attributed to the rotation of antennas.*

These horizontal phase center did not display a significant variation as a function of elevation cut-off angle. Finally, while there were no explicit vertical phase center tests, it appears that the relative vertical phase center of the antennas is within one or two mm when comparing baseline change due to different antennas.

Experiment Description

As the TRIM-CHOKE antennas were delivered to the UNAVCO facility, a subset was calibrated before being forwarded to each individual institution. This allowed for an estimate of the phase center variations within the equipment pool before they were used for field experiments. The TMGO antenna test facility was used for this calibration. Previously, UNAVCO had installed six stainless steel monuments and used them for various experiments and tests. In particular, these monuments were used for the 1995 ARI equipment tests. A map of the relative location of these monuments is contained in chapter two of the document:

UNAVCO 1995 ARI Receiver and Antenna Test Report (available via the WWW at http://www.unavco.ucar.edu/community/ari/report/)

Antenna rotation tests work well to identify inconsistencies in mean phase center offsets. By occupying a short baseline (less than 10 meters) and rotating the antenna orientation 180 degrees it is possible to see changes in the baseline length caused by the antenna phase center. For antennas of the same type, the rotation tests will highlight variations of an individual antenna relative to the pool of antennas.

Testing Schedule and Antennas Tested

Testing of the antennas began on June 1, 1996 (day of year 155) and continued until June 15, 1996 (day 170). When the first 19 of the 127 total TRIM-CHOKE antennas were shipped to the UNAVCO facility, eleven of them were used to obtain estimates of phase center variability within the equipment pool. The antenna testing schedule is shown in APPENDIX I. This table includes which marks, receivers, and antennas were used. In addition, the RINEX file name is given as well as the orientation of the antenna.

Data Processing Strategy

Individual data files were translated into RINEX format and processed using the Bernese Processing Engine(BPE). Gross outliers were detected using pseudorange observations on the zero difference level. Observations with pseudorange point positioning residuals greater than 100 meters or more than 5 times the RMS of all the residuals were deleted. Pseudorange observations above 15 degrees elevation angle were used to compute receiver clock corrections. Cycle slip repair and carrier phase editing were done on single difference files using triple difference observations.

Data were edited down to nine degrees elevation. Integer phase biases (ambiguities) were introduced for data gaps longer than five minutes and where cycle slip repair was not possible. For each observation session, all baselines were computed. This provided for redundant measurements where errors from individual antennas could be easily detected. When data from all six stations were available, 15 baselines were computed every day.

For each baseline, multiple solutions were computed. The various processing runs are summarized below.

- L1 phase solution, all observations were used (30 second sampling), and ambiguities were resolved.
- L2 phase solution, all observations were used, and ambiguities were resolved.
- L3 (ionosphere linear combination of L1 and L2 carrier phase observables) phase solution, all observations used, ambiguities from L1 and L2 processing were introduced.
- L1 phase solution, with hourly troposphere estimate at one of the two stations, all observations were used, ambiguities from L1 phase solution were introduced.
- L2 phase solution, with hourly troposphere estimates at one of the two stations, all observations were used, ambiguities from L2 phase solution were introduced.
- L3 phase solutions, with hourly troposphere estimate at one of the two stations, all observations were used, ambiguities from L1 and L2 phase solution were introduced.

In addition to the above processing schemes, baselines were computed with three different elevation cutoff angles (10, 15, and 20 degrees). For every baseline, there were 18 solutions computed.

Elevation Dependent Antenna Phase Center Variations

Anechoic chamber measurements clearly show that antenna phase centers vary as a function of the elevation and azimuth direction of the incident observation signal (See Chapter 7 of the UNAVCO ARI equipment report for examples). Often, these variations can be mis-modeled as delay due to the atmosphere. For this experiment, all the TRIM-CHOKE antennas were assumed to have the same variations. In addition, since these antennas were made to resemble other choke ring antennas, the elevation dependent variations for the Allen Osborne choke ring antenna were used in all the processing.

Because of the very short baselines computed for this experiment, and because the antennas were all the TRIM-CHOKE model, all variations with elevation and azimuth variations should difference out at the single difference level.

Estimation of Individual Phase Center Offsets

During this experiment, at least four antennas were being simultaneously tested at a time. Rotating the antenna orientations, and computing the baseline reveals the horizontal antenna phase center offset relative to the physical center of the antenna. Rotation tests with two antennas produce the average offset of both antennas. It is not possible to determine if one of the antennas has a different offset than the other. However, by using three or more antennas and rotating each one, there is enough information in the baseline component solutions to independently determine the individual horizontal offsets of each antenna. This technique provides a field test to calibrate each antenna.

Results

The phase center offsets for the eleven antennas tested are given in the following tables. Tables 2, 3 and 4 contain the L1, L2 and L3 phase center offsets computed using a 10 degree elevation cut off angle without additional troposphere parameters estimated.

Table 2: L1 Phase Centers 10 Degree Processing

SERIAL NUM	N/S	+/-	E/W	+/-
220061013	0.20 mm	0.06 mm	0.21 mm	0.08 mm
220061014	0.84	0.09	-0.32	0.12
220061015	0.15	0.06	-0.15	0.08
220061142	-0.07	0.09	0.45	0.12
220061144	-0.24	0.06	0.46	0.09
220061147	0.12	0.07	0.18	0.10

Table 2: L1 Phase Centers 10 Degree Processing

SERIAL NUM	N/S	+/-	E/W	+/-
220061149	0.61	0.07	0.27	0.09
220062100	0.21	0.08	-0.06	0.11
220062103	0.35	0.08	0.16	0.11
220062109	0.80	0.08	-0.68	0.11
220062112	0.08	0.08	0.08	0.11

Table 3: L2 Phase Centers 10 Degree Processing

SERIAL NUM	N/S	+/-	E/W	+/-
220061013	-0.16 mm	0.06 mm	0.30 mm	0.08 mm
220061014	0.28	0.08	0.62	0.11
220061015	-0.56	0.06	0.56	0.08
220061142	-0.53	0.08	-0.52	0.11
220061144	-0.21	0.06	-0.24	0.08
220061147	0.28	0.07	-0.30	0.09
220061149	-0.01	0.06	0.35	0.09
220062100	-0.49	0.07	0.38	0.10
220062103	-0.26	0.07	-0.02	0.10
220062109	0.33	0.07	-0.81	0.10
220062112	-0.27	0.07	0.18	0.10

Table 4: L3 Phase Centers 10 Degree Processing

SERIAL NUM	N/S	+/-	E/W	+/-
220061013	0.72 mm	0.11 mm	0.12 mm	0.11 mm
220061014	1.66	0.15	-1.77	0.15
220061015	1.30	0.11	-1.27	0.11
220061142	0.68	0.15	1.87	0.15

Table 4: L3 Phase Centers 10 Degree Processing

SERIAL NUM	N/S	+/-	E/W	+/-
220061144	-0.29	0.11	1.57	0.11
220061147	-0.05	0.13	0.86	0.13
220061149	1.62	0.12	0.11	0.12
220062100	1.17	0.14	-0.72	0.14
220062103	1.46	0.14	0.40	0.14
220062109	1.42	0.14	-0.45	0.14
220062112	0.72	0.14	-0.12	0.14

Tables 5, 6 and 7 contain the L1, L2 and L3 phase center offsets computed using a 15 degree elevation cut off angle.

Table 5: L1 Phase Centers 15 Degree Processing

SERIAL NUM	N/S	+/-	E/W	+/-
220061013	0.15 mm	0.05 mm	0.25 mm	0.05 mm
220061014	0.80	0.05	-0.25	0.05
220061015	0.20	0.05	-0.17	0.04
220061142	-0.05	0.08	0.38	0.07
220061144	-0.25	0.05	0.51	0.05
220061147	0.15	0.06	0.15	0.06
220061149	0.60	0.06	0.21	0.05
220062100	0.17	0.07	-0.01	0.06
220062103	0.37	0.07	0.10	0.06
220062109	0.80	0.07	-0.62	0.06
220062112	0.11	0.07	0.05	0.06

Table 6: L2 Phase Centers 15 Degree Processing

SERIAL NUM	N/S	+/-	E/W	+/-
220061013	-0.24 mm	0.04 mm	0.31 mm	0.05 mm
220061014	0.12	0.05	0.66	0.05
220061015	-0.50	0.04	0.52	0.05
220061142	-0.51	0.07	-0.55	0.07
220061144	-0.30	0.05	-0.21	0.05
220061147	0.31	0.05	-0.29	0.06
220061149	0.05	0.05	0.29	0.05
220062100	-0.56	0.06	0.39	0.07
220062103	-0.25	0.06	-0.04	0.07
220062109	0.22	0.06	-0.78	0.07
220062112	-0.21	0.06	0.14	0.07

Table 7: L3 Phase Centers 15 Degree Processing

SERIAL NUM	N/S	+/-	E/W	+/-
220061013	0.73 mm	0.09 mm	0.13 mm	0.07 mm
220061014	1.85	0.10	-1.67	0.07
220061015	1.24	0.09	-1.25	0.07
220061142	0.62	0.14	1.78	0.10
220061144	-0.17	0.10	1.62	0.07
220061147	-0.11	0.11	0.84	0.08
220061149	1.44	0.10	0.10	0.07
220062100	1.22	0.13	-0.61	0.09
220062103	1.43	0.13	0.38	0.09
220062109	1.64	0.13	-0.40	0.09
220062112	0.63	0.13	-0.08	0.09

Tables 8, 9 and 10 contain the L1, L2 and L3 phase center offsets computed using a 20 degree elevation cut off angle.

Table 8: L1 Phase Centers 20 Degree Processing

SERIAL NUM	N/S	+/-	E/W	+/-
220061013	0.14 mm	0.05 mm	0.23 mm	0.07 mm
220061014	0.79	0.05	-0.22	0.07
220061015	0.19	0.05	-0.14	0.07
220061142	-0.05	0.07	0.37	0.10
220061144	-0.24	0.05	0.48	0.07
220061147	0.18	0.06	0.18	0.09
220061149	0.60	0.05	0.30	0.08
220062100	0.15	0.07	-0.02	0.10
220062103	0.42	0.07	0.16	0.10
220062109	0.77	0.07	-0.65	0.10
220062112	0.13	0.07	0.09	0.10

Table 9: L2 Phase Centers 20 Degree Processing

SERIAL NUM	N/S	+/-	E/W	+/-
220061013	-0.23 mm	0.05 mm	0.30 mm	0.07 mm
220061014	0.12	0.05	0.67	0.07
220061015	-0.55	0.05	0.54	0.07
220061142	-0.55	0.07	-0.54	0.10
220061144	-0.27	0.05	-0.24	0.07
220061147	0.33	0.06	-0.29	0.08
220061149	0.03	0.05	0.34	0.07
220062100	-0.55	0.06	0.39	0.09
220062103	-0.29	0.06	-0.02	0.09
220062109	0.20	0.06	-0.81	0.09

Table 9: L2 Phase Centers 20 Degree Processing

SERIAL NUM	N/S	+/-	E/W	+/-
220062112	-0.21	0.06	0.14	0.09

Table 10: L3 Phase Centers 20 Degree Processing

SERIAL NUM	N/S	+/-	E/W	+/-
220061013	0.70 mm	0.09 mm	0.13 mm	0.09 mm
220061014	1.81	0.09	-1.59	0.09
220061015	1.37	0.09	-1.25	0.09
220061142	0.72	0.13	1.71	0.13
220061144	-0.19	0.09	1.62	0.09
220061147	-0.05	0.11	0.89	0.11
220061149	1.51	0.10	0.27	0.10
220062100	1.24	0.12	-0.63	0.13
220062103	1.54	0.12	0.43	0.13
220062109	1.67	0.12	-0.38	0.13
220062112	0.68	0.12	-0.01	0.13

The above tables show that for a single baseline component, the horizontal phase centers of the TRIM-CHOKE antennas tested are within 1.8 mm (for the L3 solutions) of the physical center of the antenna in both horizontal components. In addition, the L1 and L2 phase center offsets components are within 1.0 mm of the physical center of the antenna.

Without an independent ground truth survey good to less than one millimeter, there are no current ways of estimating the absolute vertical phase center of an antenna. Instead, only relative phase center differences can be seen. From these tests, it appears as if the TRIM-CHOKE antennas have vertical phase centers that agree to one millimeter or less. Figure 3, shows the height scatter for baselines between mark DE01 and other marks. During these tests, there were two different antennas on this mark. The first 16 solutions are with antenna 22006101. The mean height difference of these solutions relative to the best estimate of ground truth is 0.06 mm. The last 19 solutions are with antenna 22062109 on mark DE01. The mean height difference of these solutions relative to the best estimate of ground truth is 0.5 mm. From these solutions, it appears that the vertical phase centers agree to within one millimeter.

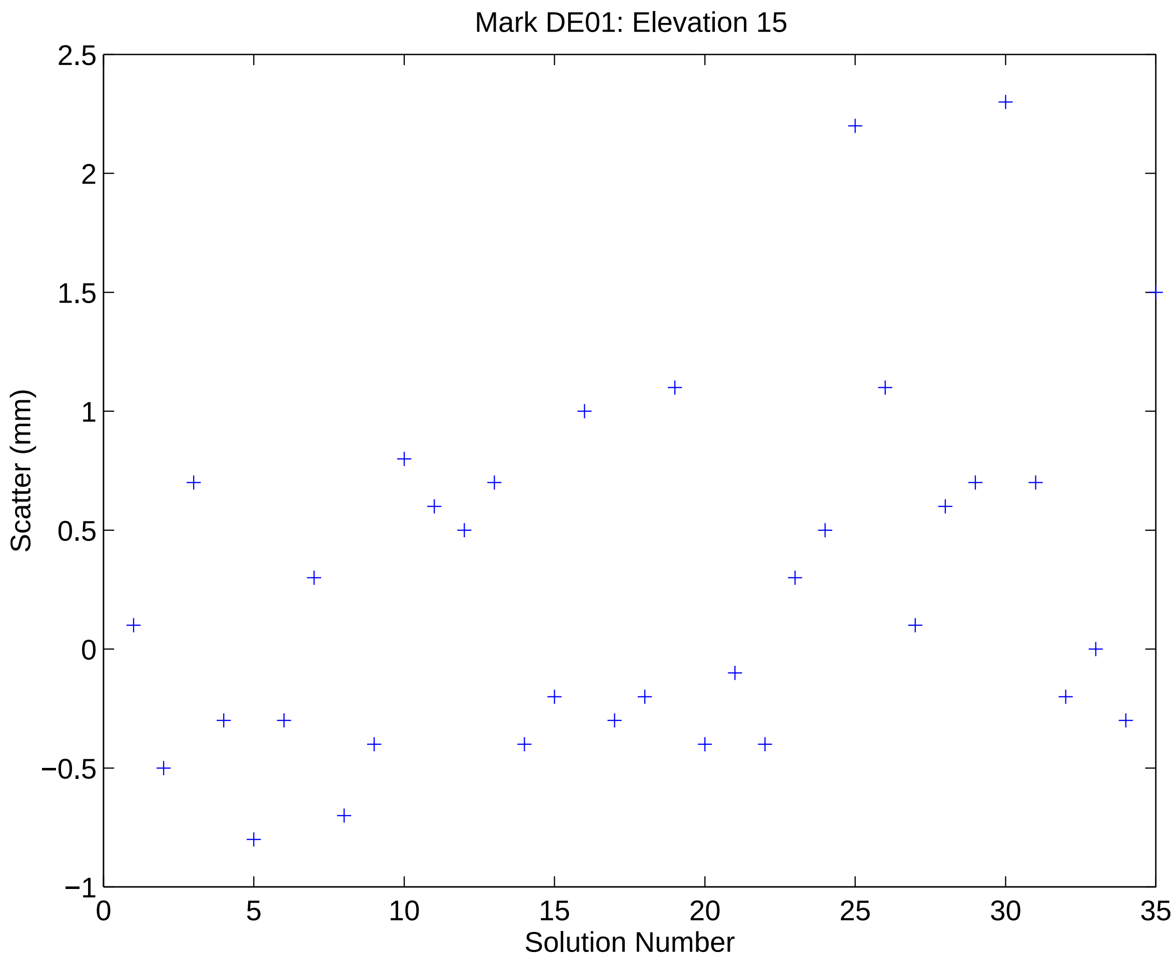

Figure 3:Height scatter for baselines relative to mark DE01. For the first 16 solutions, antenna 220061014 was on the mark, the average of these solutions is 0.06mm. For the last 19 solutions, antenna 22062109 was on the mark, the average of these solutions is 0.5mm. From these baseline height solutions, it appears that the relative heights of the two antenna phase centers are within one mm of each other.

All baselines were computed using three different elevation cutoff angles. This was done to see if the average phase center varied as a function of elevation cutoff angle. Figure 4 displays the height component scatter of all baselines made from antenna 220061015. The three symbols represent the solutions from the three different minimum elevation angles used in the processing. All vertical scatter was less than +/- 1.5 mm. This was typical of all antennas and implies that the vertical antenna phase center offsets are relatively consistent.

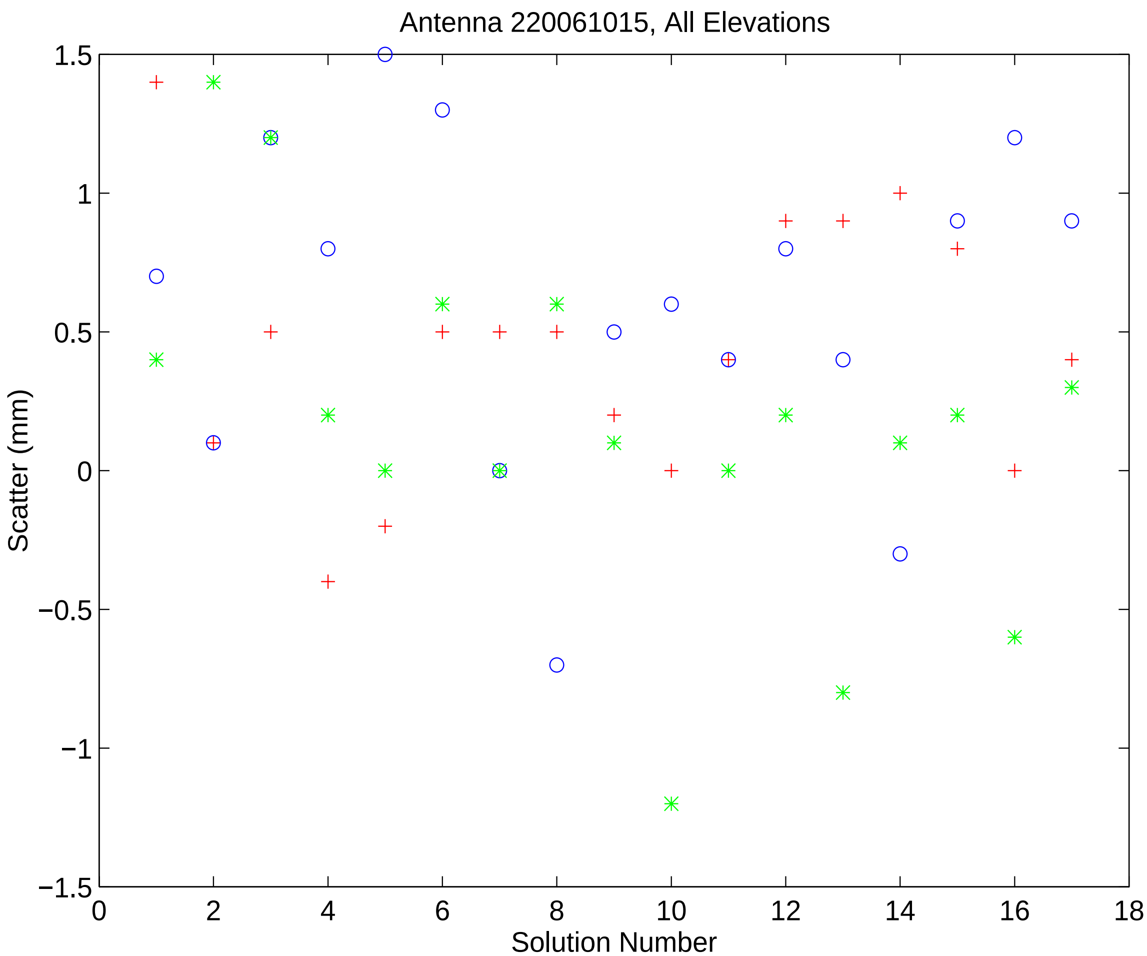

Figure 4:Height scatter for antenna 220061015. The blue "o" symbols represent solutions using a 10 degree elevation cutoff, the red "+" symbols use a 15 degree cutoff, the green "" symbols use a 20 degree cutoff. The scatter of these height solutions is the scatter about the mean of all the solutions. From this plot it appears as if the phase center does not vary as a function of elevation cutoff angle.*

Conclusions

From the eleven antennas tested in the UNAVCO equipment pool, each component of the TRIM-CHOKE antennas shows an L3 horizontal phase center variability of less than 1.8 mm. These phase centers also appear to be relatively constant (changes are less than 10%) between elevation cutoff angles of 10, 15, and 20 degrees. In addition, it is also possible to estimate individual horizontal phase centers using three or more antennas, and rotating them 180 degrees. Without very accurate (better than one millimeter) independent ground truth surveys, it is impossible to determine the absolute vertical phase center offsets of the antennas. It is possible to obtain a measure of the relative differences between antennas by comparing baseline height solutions using a different antenna at one end of the baseline and the same antenna on the other end. From this analysis, the phase centers of the TRIM-CHOKE antennas appear to be consistent to within one millimeter in the vertical component.

The variability of the horizontal phase centers appears to be similar to the AOA choke ring antennas within the UNAVCO NASA/DOSE equipment pool. Previous tests to determine the antenna consistency within a model type at UNAVCO, shows that the AOA choke ring antenna have a horizontal variation of approximately 1.5 mm for the L3 phase center. These results were presented at the 1994 Fall AGU, and can be downloaded through UNAVCO's anonymous ftp.

APPENDIX I

Day	RINEX FILE	MARK	RX#	Receiver Type	Antenna Type	V.HGT	ORIEN	ANT #
155	DE011550.96O	DE01	15413	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.4033	NORTH	0220061014
155	DN011550.96O	DN01	15269	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.4006	NORTH	0220061144
155	DS011550.96O	DS01	15413	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3979	NORTH	0220061015
155	DW011550.96O	DW01	15404	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3954	NORTH	0220061142
155	EE011550.96O	EE01	14455	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3862	NORTH	0220061013
155	WW011550.96O	WW01	15412	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3734	NORTH	0220061147
156	DE011560.96O	DE01	15413	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.4031	SOUTH	0220061014
156	DN011560.96O	DN01	15269	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.4006	SOUTH	0220061144
156	DS011560.96O	DS01	15413	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3979	NORTH	0220061015
156	DW011560.96O	DW01	15404	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3954	NORTH	0220061142
156	EE011560.96O	EE01	14455	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3861	SOUTH	0220061013
156	WW011560.96O	WW01	15412	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3735	NORTH	0220061147
157	DE011570.96O	DE01	15413	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.4031	NORTH	0220061014
157	DN011570.96O	DN01	15269	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.4006	NORTH	0220061144
157	DS011570.96O	DS01	15413	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3979	SOUTH	0220061015
157	DW011570.96O	DW01	15404	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3954	SOUTH	0220061142
157	EE011570.96O	EE01	14455	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3861	NORTH	0220061013
157	WW011570.96O	WW01	15412	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3735	SOUTH	0220061147
158	DE011580.96O	DE01	15413	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.4031	NORTH	0220061014
158	DN011580.96O	DN01	15269	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.4006	NORTH	0220061144
158	DS011580.96O	DS01	15413	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3979	SOUTH	0220061015
158	DW011580.96O	DW01	15404	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3949	SOUTH	0220061149
158	EE011580.96O	EE01	14455	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3861	NORTH	0220061013
159	DE011590.96O	DE01	15413	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.4031	NORTH	0220061014
159	DN011590.96O	DN01	15269	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.4006	NORTH	0220061144
159	DS011590.96O	DS01	15413	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3979	SOUTH	0220061015
159	DW011590.96O	DW01	15404	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3949	SOUTH	0220061149
159	EE011590.96O	EE01	14455	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3861	NORTH	0220061013
160	DE011600.96O	DE01	15413	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.4031	NORTH	0220061014
160	DN011600.96O	DN01	15269	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.4006	NORTH	0220061144
160	DS011600.96O	DS01	15413	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3979	SOUTH	0220061015
160	DW011600.96O	DW01	15404	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3949	SOUTH	0220061149
160	EE011600.96O	EE01	14455	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3861	NORTH	0220061013
161	DE011610.96O	DE01	15413	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3999	SOUTH	0220061014
161	DN011610.96O	DN01	15269	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.4006	SOUTH	0220061144
161	DS011610.96O	DS01	15413	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3979	NORTH	0220061015
161	DW011610.96O	DW01	15404	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3949	NORTH	0220061149
161	EE011610.96O	EE01	14455	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3861	SOUTH	0220061013
162	DE011620.96O	DE01	15413	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3999	SOUTH	0220061014
162	DN011620.96O	DN01	15269	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.4006	SOUTH	0220061144
162	DS011620.96O	DS01	15413	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3979	NORTH	0220061015
162	DW011620.96O	DW01	15404	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3949	NORTH	0220061149
162	EE011620.96O	EE01	14455	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3861	SOUTH	0220061013
162	WW011620.96O	WW01	15412	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3735	NORTH	0220061147
163	DE011630.96O	DE01	15413	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3999	NORTH	0220061014
163	DN011630.96O	DN01	15269	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.4004	NORTH	0220061144
163	DS011630.96O	DS01	15413	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3979	SOUTH	0220061015
163	DW011630.96O	DW01	15404	TRIMBLE 4000SSI	TRIMBLE CHOKE RING	1.3949	SOUTH	0220061149

163	EE011630.96O	EE01	14455	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3861	NORTH	0220061013
163	WW011630.96O	WW01	15412	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3735	SOUTH	0220061147
164	DE011640.96O	DE01	15413	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3999	NORTH	0220061014
164	DN011640.96O	DN01	15269	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.4004	NORTH	0220061144
164	DS011640.96O	DS01	15413	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3979	NORTH	0220061015
164	DW011640.96O	DW01	15404	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3949	NORTH	0220061149
164	EE011640.96O	EE01	14455	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3861	NORTH	0220061013
165	DE011650.96O	DE01	15413	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3999	NORTH	0220062109
165	DN011650.96O	DN01	15269	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.4005	NORTH	0220062112
165	DS011650.96O	DS01	15413	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3980	NORTH	0220062100
165	DW011650.96O	DW01	15404	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3949	NORTH	0220062103
165	EE011650.96O	EE01	14455	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3861	NORTH	0220061013
165	WW011650.96O	WW01	15412	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3732	NORTH	0220061147
166	DE011660.96O	DE01	15413	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3998	SOUTH	0220062109
166	DN011660.96O	DN01	15269	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.4005	NORTH	0220062112
166	DS011660.96O	DS01	15413	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3978	SOUTH	0220062100
166	DW011660.96O	DW01	15404	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3949	NORTH	0220062103
166	EE011660.96O	EE01	14455	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3861	SOUTH	0220061013
166	WW011660.96O	WW01	15412	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3732	NORTH	0220061147
167	DE011670.96O	DE01	15413	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3998	NORTH	0220062109
167	DN011670.96O	DN01	15269	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.4004	SOUTH	0220062112
167	DS011670.96O	DS01	15272	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3978	NORTH	0220062100
167	DW011670.96O	DW01	15404	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3949	SOUTH	0220062103
167	EE011670.96O	EE01	14455	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3861	NORTH	0220061013
167	WW011670.96O	WW01	15412	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3732	SOUTH	0220061147
168	DE011680.96O	DE01	15413	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.4003	NORTH	0220062109
168	DN011680.96O	DN01	15269	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.4004	SOUTH	0220062112
168	DS011680.96O	DS01	15272	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3978	NORTH	0220062100
168	DW011680.96O	DW01	15404	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3949	SOUTH	0220062103
168	EE011680.96O	EE01	14455	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3861	SOUTH	0220061147
168	WW011680.96O	WW01	15412	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3732	NORTH	0220061013
169	DE011690.96O	DE01	15413	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3999	SOUTH	0220062109
169	DN011690.96O	DN01	15269	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.4004	NORTH	0220062112
169	DS011690.96O	DS01	15272	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3979	SOUTH	0220062100
169	DW011690.96O	DW01	15404	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3949	NORTH	0220062103
169	EE011690.96O	EE01	14455	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3861	SOUTH	0220061013
169	WW011690.96O	WW01	15412	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3733	NORTH	0220061147
170	DE011700.96O	DE01	15413	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3999	NORTH	0220062109
170	DN011700.96O	DN01	15269	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.4004	NORTH	0220062112
170	DS011700.96O	DS01	15272	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3978	NORTH	0220062100
170	DW011700.96O	DW01	15404	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3947	NORTH	0220062103
170	WW011700.96O	WW01	15413	TRIMBLE 4000SSI TRIMBLE CHOKE RING	1.3732	NORTH	0220061147