The Effect of Antenna Covers On GPS Baseline Solutions

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Abstract

With the increasing number of permanent GPS monuments being deployed, many investigators are adding covers over antennas to prevent snow accumulation, reduce the amount of wear on antennas, and discourage animals from disturbing the antenna. UNAVCO has tested some of these covers and has designed a model that minimizes their effect on baseline estimation.

From the tests presented here, it is shown that antenna covers cause an additional delay on the GPS signal that effects the height component of a GPS baseline solution. The errors introduced can change baseline height solutions between 2 mm and 40 mm depending on the cover type, the antenna type, and the elevation cutoff angle used for data processing. Of the two shapes of antenna covers tested, the ones with a conical shape have the largest effect. Covers shaped like a hemispherical dome have a smaller effect, especially when they are mounted so that the antennas's mean phase center is positioned in the center of the cover. The thickness of the cover is also important. The thinner the cover, the smaller the effect. Finally, there does appear to be an effect caused by the material used to make the cover, but this has the smallest effect of all the variables described above.

The results from these tests also show that the mounting apparatus of the cover can also have an effect on the phase center of an antenna. In particular, mounting the cover on a metal base plate will drastically increase the near field reflections around the antenna, [Elosegui et al., 1995] causing errors of up to 10 mm in the baseline height solution.

While not seen in these tests, results from continuous networks in Scandinavia show that antenna covers can cause up to a 10 mm level effect in the horizontal baseline components (Jim Davis, personal communication, 1996).

Introduction

During the 1995 UNAVCO ARI Receiver and Antenna Tests, measurements of antenna phase and amplitude variations were taken at Ball Aerospace using their anechoic chamber. These results were presented in chapter 7 of the receiver report by Rocken et al (1995). When UNAVCO tested these antennas, Ashtech had begun offering a choke ring antenna that was manufactured to be similar to the Allen Osborne Associates (AOA) Dorne Margolin T choke ring. The AOA antenna is generally assumed to be the standard within the UNAVCO community because it is used at most of the permanent sites in the International GPS Service for Geodynamics (IGS) global tracking network. While the Ashtech antenna was similar to the AOA antenna, it came equipped with an additional protective raydome. When the tests from the anechoic chamber were completed, the results showed that the Ashtech Dorne Margolin choke ring antenna had a different phase pattern than the AOA antenna. The difference in phase patterns of the two antennas was approximately 15% and was assumed to be caused by the raydome cover. This lead to an experiment where a very short baseline was measured using two Ashtech choke ring antennas with the raydome mounted on only one of the antennas. The results of this test (see Chap 7 of ARI Report) showed a 15 mm bias in the vertical baseline component, and was verified by Niell (1995).

As the UNAVCO facility became increasingly involved in the deployment of permanent GPS stations, the facility soon realized that many permanent GPS monuments require some type of cover over the antenna to protect it from weather, animals, and general wear and tear. Some manufactures, including Ashtech and Trimble, now sell antenna covers for this purpose. Also, principal investigators have been designing and deploying covers of their own designs. With the results of the Ashtech dome tests reported in the ARI report, the facility decided that further tests needed to be conducted to determine what effect these covers have on baseline solutions.

The facility tested two general shapes of covers. One of the shapes was conical while the other was spherical. Ashtech and Trimble both offer conical covers, but they are made of different materials and do not mount over the antenna in the same way. UNAVCO has made a spherical cover using two different thicknesses of acrylic (one-eighth inch and one-quarter inch). We tested all these designs, and report their effects in this report.

The domes were tested by measuring very short baselines (<10 meters) with and without a cover on one of the antennas. The data were then analyzed with different estimation parameters and elevation cutoff angles. The solutions were then compared to a "ground truth" measurement to determine the effect the cover has on the baseline solution.

Results of these tests show that when an antenna cover is used at one end of the baseline, the height component of the solution is different from ground truth. These problems are amplified by estimation of tropospheric parameters, which produce errors in tropospheric delay as well as station height. The shape and design of the covers appears to vary the magnitude of the effect. The conical covers produce vertical errors of up to 44 mm, while the thin spherical domes appear to minimize the problem and produce an error of a few millimeters or less. The solutions also have a strong dependence on variations in the elevation cutoff angle.

These tests also point out the fact that it is important to mount the cover on or around the antenna in such a way as to minimize multipath. For example, a metal plate like the one provided with the Trimble conical cover has up to a 20 mm effect in the height component, whereas mounting the cover using some sort of plastic or acrylic plate produces an effect of less than a few millimeters.

Experiment Description

The general way of testing these covers is to occupy a baseline with two antennas of the same model. This baseline is measured for one or two days without any protective covering. Once the local error sources have been characterized for that baseline, a cover is mounted over one of the antennas. The differences between the solutions with and without the cover can be assumed to be caused by the cover. For short baselines, like the ones in these tests, a pair of similar covers mounted over both of the antennas produces a common mode error that would difference out on the single difference level (the observations between two stations, and one satellite).

Two locations were used for these tests. The first was the roof of the UNAVCO facility, the second was near the Table Mountain Gravity Observatory (TMGO). Once the data was collected, it was processed using various schemes. In general, the data processing is described below.

Data Processing and Analysis 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.

Carrier phase 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 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 free 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). This report summarizes the results by presenting only the L3 solutions with and without additional troposphere parameter estimation. These two solutions represent the two most common ways that high accuracy GPS baseline solutions are computed. Also, the errors in these solutions are products of the errors in the other solution types.

After processing the GPS data, the baseline components were compared to a "ground truth". Generally, conventional surveying techniques provide measurements accurate to a few millimeters. For the type of antenna tests conducted here, it would be desirable to compare the solutions to a ground truth that is precise to less than one millimeter. This is accomplished by computing a ground truth using GPS. For short baselines less than a few tens of meters, a network of the same type of GPS receivers and antennas set up to minimize multipath, and processed using only the L1 phase observations will produce results repeatable to a less than 1 mm. This is as good, if not better than conventional surveying results. UNAVCO has conducted this type of calibration ground truth survey for the marks use in these tests. In addition, the calibration survey has been repeated several times over the past year and the agreement between surveys is better than one millimeter for most of the monuments.

Antenna Covers Tested

Four different antenna covers were tested by UNAVCO. These covers are shown below. The Ashtech conical cover and the one-quarter inch spherical dome cover were tested on the roof of the UNAVCO facility. The Trimble conical cover, and the one-eighth inch spherical dome were tested at TMGO.

+ The Ashtech conical cover is shown in figure 1. The cover is conically shaped and is mounted on to the antenna using a set of plastic (nonconducting) screws. There is no metal or conducting surface that is part of the antenna cover.

Figure 1: *Ashtech conical cover mounted on their Dorne Margolin choke ring antenna.*

+ The Trimble conical cover is shown in figure 2. The cover mounts on to a metal plate under the antenna. Figure 2 shows the antenna cover mounted over a Trimble Dorne Margolin choke ring antenna, and the mounting plate under the choke ring antenna.

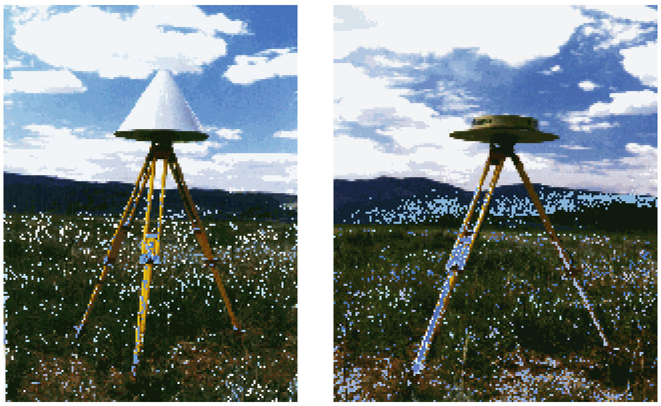

Figure 2: *The left picture shows a Trimble conical cover with metal mounting plate, using a Trimble Dorne Margolin choke ring antenna. The picture on the right is of the Trimble Dorne Margolin choke ring antenna and the mounting plate for the cover.*

+ The one-eighth inch acrylic spherical dome is shown in figure 3. The dome is mounted so that the phase center sits in the center of the dome in the left picture. In the right picture, the phase center is not centered in the middle of the antenna cover. The plexiglass plate under the antenna in the picture on the right was not part of the cover, and did not effect the solutions.

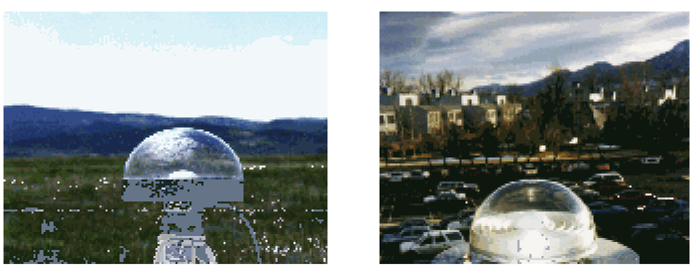

Figure 3: *Prototype one-eighth inch conical covers from UNAVCO. The left picture is of the UNAVCO spherical dome mounted so that the mean phase center is in the center of the spherical dome. The picture on the right has the spherical dome mounted slightly lower on the antenna, so that the phase center is no longer in the center of the dome*

+ The one-quarter inch acrylic spherical dome is shown in figure 4. The dome is mounted onto the plexiglass plate under the antenna. The phase center of the antenna is not centered in the middle of the spherical cover.

Figure 4: *A prototype one-quarter inch spherical cover mounted on a plexiglass plate. This spherical dome is mounted on the plate such that the phase center is not located at the center of the dome.*

Results

The results from these tests indicate that all of the covers have an effect on the height component of the estimated baseline length. However, the magnitude of the effect varies greatly with the type of cover, and what elevation cutoff angle was used in the processing.

Figure 5 shows results using the Trimble conical cover with their Dorne Margolin choke ring antenna. Results using 10, 15, and 20 degrees as the data processing cutoff angle are shown in the top, middle, and bottom panels. The green "+" marks indicate L3 height solutions. Red "*" marks indicate L3 height solutions with additional troposphere parameters estimated at one of the sites. For days 170, 177, and 178 neither the raydome cover or the metal mounting plate are attached to the antenna. Days 171, 172, 175, and 176 have the metal plate mounted underneath the antenna without the conical dome attached. Days 173 and 174 have the dome and the conical cover mounted on one of the antennas.

A few conclusions can be made from results presented in the figure. The first is that the conical dome causes a vertical height bias that is amplified by the estimation of a troposphere estimate. Days 173 and 174 have the conical dome, and the metal mounting plate, on one of the antennas. On these days, the height component of the solutions disagree with ground truth by up to 20 mm. A second conclusion is that the magnitude of the disagreement varies as a function the elevation cutoff angle used for processing, particularly when solutions with tropospheric delay parameters are estimated. Again, for days 173 and 174 when the conical dome is mounted on one of the antennas, the height solution varies by almost 30 mm when comparing solutions using a 10 and 20 degree elevation cut off. The third conclusion is that the metal ground plane which is mounted underneath the antenna also causes a bias in the height component of the solutions. The metal plate was mounted underneath one of the antennas without the conical dome on days 172, 173, 175, and 176. Biases ranging from 2 mm for 10 degree elevation cutoff to

5 mm for 20 degree elevation cutoff when compared to ground truth are evident for solutions without troposphere estimates. For solutions with troposphere estimates, variations of up to 10 mm (for troposphere solutions using a 20 degree cutoff angle) from ground truth on these days can be attributed to this extra piece of metal.

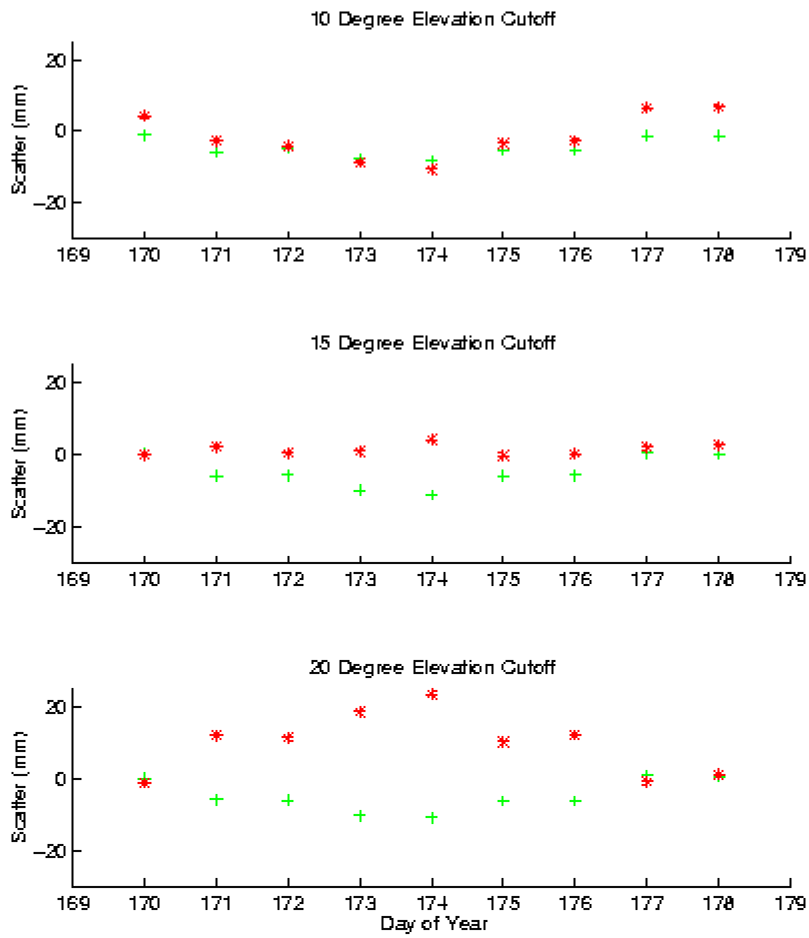

Figure 5: *Baseline height solutions using the Trimble Dorne Margolin choke ring antenna and the Trimble conical cover dome. The top figure uses an elevation cutoff angle of 10 degrees, the second figure uses an elevation cutoff angle of 15 degrees, and the bottom figure uses an elevation angle of 20 degrees. In all figures, the green "+" symbols represent L3 height solutions. The red "*" symbols represent L3 height solutions with additional site specific troposphere parameters estimated. On days 170, 177, and 178 nothing was surrounding the antennas. On days 171, 172, 175, and 176 the metal base plate was installed underneath one of the antennas. On days 173 and 174 the Trimble conical shaped dome was attached to the base plate under one of the antennas.*

The results in figure 5 use a Trimble Dorne Margolin choke ring antenna and their conical cover with metal mounting plate. To confirm that the problems seen with the choke ring antenna would occur with other antenna types, five days of data were collected with the Trimble L1/L2 GEOD GP antenna. The results of this test are plotted in figure 6. The three panels in this figure represent three different elevation angles used in processing the data. The top panel uses a 10 degree elevation mask, the middle panel uses a 15 degree elevation mask, and the bottom panel uses a 20 degree elevation mask. The green "+" symbols are the L3 height solutions, and the red "*" symbols represent L3 height solutions with additional troposphere parameters estimated at one site. Days 179 and 180 are control surveys. For these two days, only the antennas were mounted on the tripod. Solutions without troposphere parameters estimated agree to within 1 mm of ground truth while solutions with troposphere parameters estimated agree to within 5mm. Days 181, 182, and 183 have the conical dome and metal ground plate attached to one of the antennas.

Both types of height solutions in figure 6 can be seen to disagree with ground truth surveys by at least 20 mm. In particular, the L3 solutions without troposphere estimates (the green "+" symbols) seem to have a 20 mm height bias throughout all elevation cutoff angles. The 20 mm offset occurs in both the L3 solutions (with and without troposphere parameters estimated) and is consistent through all the elevation cutoff angles. This is similar to figure 5. For the days where the mounting plate only is attached to the antenna, the height errors are consistently in the 5 mm range. This implies that the errors are introduced by the metal mounting plate. Comparing figures 5 and 6, the metal mounting plate has a larger effect on solutions using the Trimble L1/L2 GEOD GP antenna than the Dorne Margolin choke ring antenna. In addition to the 20 mm offset caused by the mounting plate, the rest of the errors in figure 6 can be attributed to the cover. The L3 solutions with troposphere estimates vary as a function of elevation cutoff angle with the largest differences (44 mm) when compared to ground truth occurring when a 20 degree elevation cutoff angle is used. The results with troposphere estimates show that the solutions vary as the elevation cutoff mask is changed. In particular, the solutions with a 20 degree elevation cutoff have a height error of 44 mm.

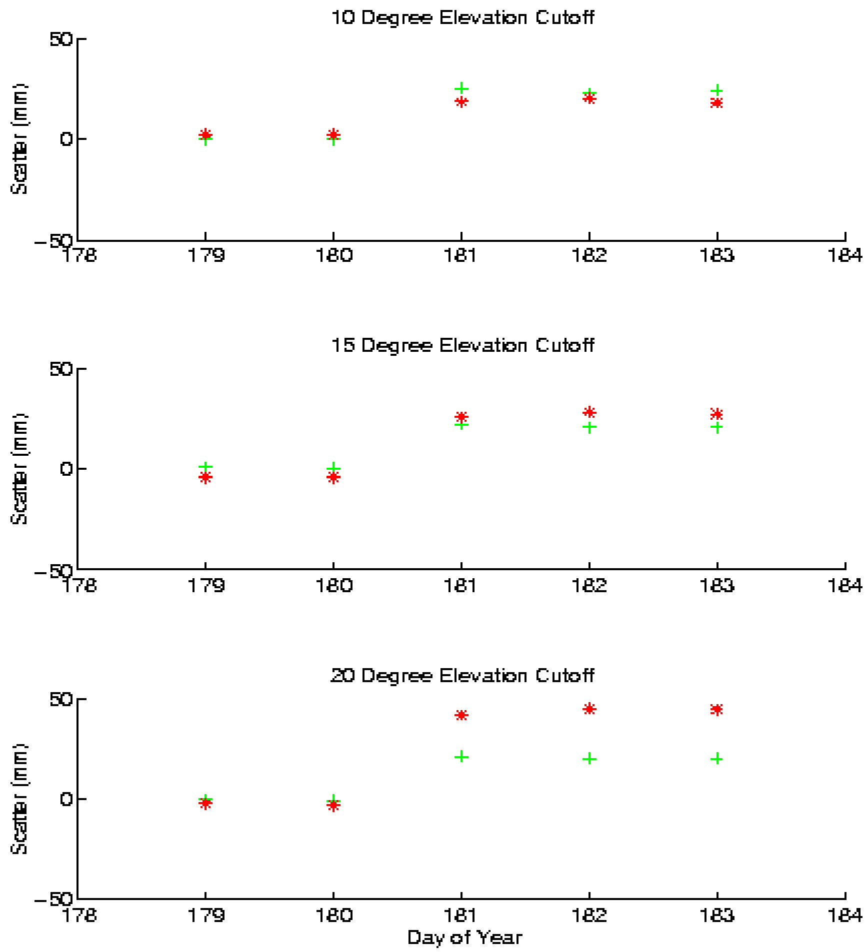

Figure 6: *Baseline height solutions using the Trimble GEOD L1/L2 GP antenna and the Trimble conical antenna cover. The top figure uses an elevation cutoff angle of 10 degrees, the second figure uses an elevation cutoff angle of 15 degrees, and the bottom figure uses an elevation angle of 20 degrees. In all figures, the green "+" symbols represent L3 height solutions. The red "*" symbols represent L3 height solutions with additional site specific troposphere parameters estimated. Days 179 and 180 are solutions without the cover on either antenna. Days 181, 182, and 183 are solutions with the Trimble conical antenna cover on one of the antennas.*

Ashtech Dorne Margolin choke ring antennas come equipped with a conical dome mounted directly over the antenna. Effects of the dome on the antenna can be seen in figure 7. The top panel shows solutions using an elevation cutoff of 15 degrees, while the second panel uses an elevation cutoff of 20 degrees. The red "+" symbols represent L3 height solutions, while the green "*" symbols represent L3 height solutions with troposphere estimates. Days 041, 042, and 048 through 051 do not have a dome on either antenna. Days 044 and 045 have a dome on one of the two antennas. For days 046 and 047 the dome was removed from the first antenna and moved to the second antenna. Like the Trimble conical antenna cover, the Ashtech cover clearly causes an L3 height solution that differs from the ground truth surveys. This error is as much as 20 mm when estimating troposphere parameters, using an elevation cutoff of 20 degrees. Looking at the two plots, there appears to be a bias between the solutions with troposphere estimates and the solutions without troposphere estimates. This is probably because multipath at the two stations are not identical at the two antennas, and the difference is mismodeled as tropospheric delay. If one looks at only the troposphere solutions, they seem to be centered around a value of 2 or 3 mm for the 15 degree solutions and 6 or 7 mm for the 20 degree solutions.

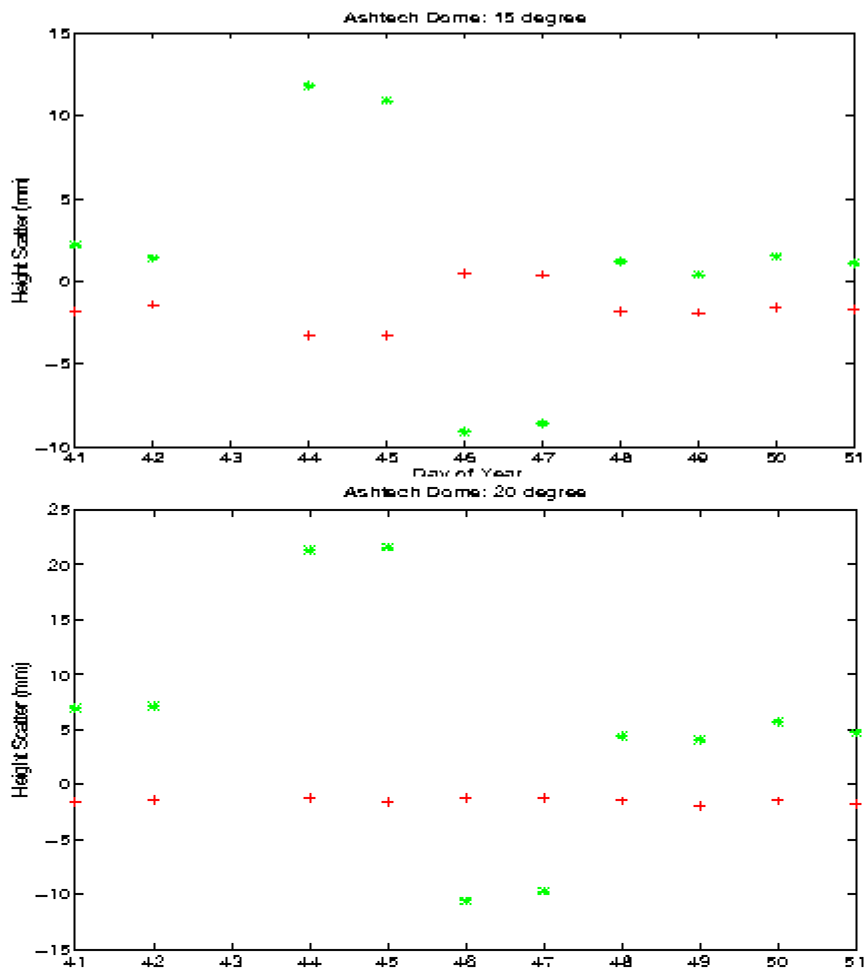

Figure 7: *Baseline height solutions using the Ashtech Dorne Margolin choke ring antenna and the Ashtech conical antenna cover. The top figure uses an elevation cutoff angle of 15 degrees, the second figure uses an elevation cutoff angle of 20 degrees. In both figures, the red "+" symbols represent L3 solutions. The green "*" symbols represent L3 solutions with site specific troposphere parameters estimated. The solutions on days 041, 042, 048, 049, 050 and 051 do not have a cover on either antenna. Solutions on days 044 and 045 have the conical dome on one of the two mark. The dome was switched to the other mark for days 046 and 047.*

The one-eighth inch acrylic spherical dome has a much smaller effect than either of the conical covers reported above. The results for this dome are shown in figure 8. In this plot only L3 height solutions without troposphere parameters estimated are plotted. The L3 troposphere solutions are not plotted because the noise introduced by adding additional troposphere parameters masks the results shown in the L3 solutions without troposphere estimates. The red "+" symbols represent solutions using a 10 degree elevation cutoff, the blue "*" symbols use a 15 degree elevation cutoff, the green "o" symbols represent solutions with 20 degree elevation cutoff. Days 170, 171, and 172 were control days where the antennas were mounted without any covers. Days 173 and 174 are solutions where a one-eighth inch spherical acrylic dome was mounted in a non-concentric manner over one of the antennas. Days 175 and 176 have the acrylic dome mounted over the same antenna, but this time so that the nominal phase center is located as near as possible to the center of the dome. Days 177 and 178 the dome was removed from the antenna to check how well the control survey could be repeated. It appears as if the solution on day 173 is an outlier and that the rest of the solutions show that the one-eighth inch acrylic dome causes at most a 2 mm offset in the baseline height solution. In addition, there was no dependence of troposphere estimation on these solutions.

Day 173 appears to be an outlier because the solutions between days 173 and 174, where the dome was mounted non concentrically over one of the antennas, differ by approximately 3mm. This difference in these two solutions is more than three times the difference of all the other solution differences of similar antenna/dome configurations. The reason 173 appears to be the problem, instead of 174, is that the solution on day 174 has the same sign change as days 175 and 176. The differences between days 173 and 174 versus 175 and 176 is that the cover was moved so that it was positioned concentrically over the antenna. It is doubtful that the difference between the concentric and non-concentric setup would be severe enough to cause a complete sign change in the effect on baseline height. The results for day 173 have been checked for a blunder multiple times, and none has been found. However, the consistency in the rest of the solutions seems to suggest that something is different for this day.

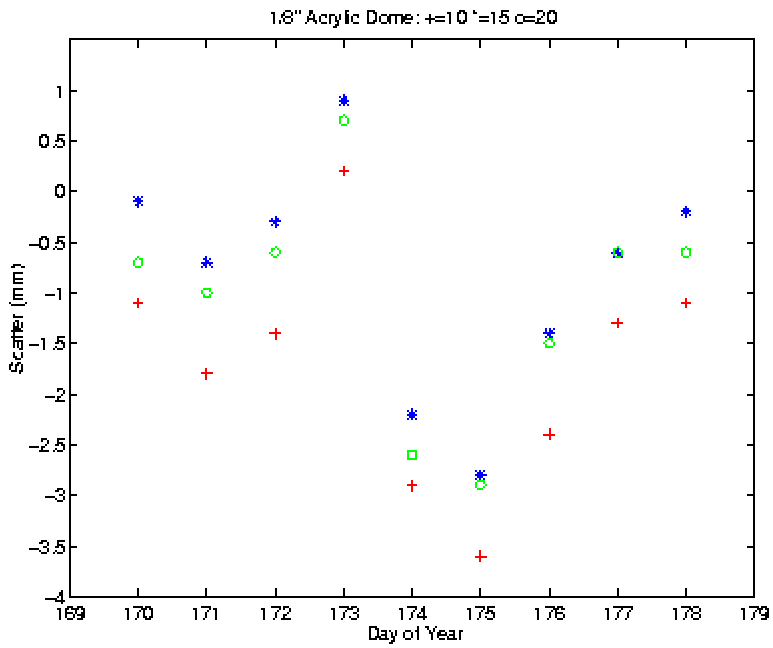

Figure 8: *Baseline height solutions for the one-eighth inch spherical acrylic cover. The red "+" symbols represent solutions using a 10 degree elevation cutoff, blue "*" symbols use a 15 degree cutoff, green "o" symbols use a 20 degree cutoff. All solutions are without troposphere estimation. The noise in the solutions with additional troposphere parameters estimated was too large to see the small changes associated with this figure. Solutions on days 170, 171 and 172 have no antenna covers on either antenna. Solutions on days 173 and 174 have an acrylic dome mounted in a non-concentric way over one of the antennas. Solutions on days 175 and 176 have the dome mounted so that the dome is concentric with respect to the mean phase center of the antenna. The solutions on days 177 and 178 do not have a cover over either of the antennas.*

Tests of the one-quarter inch dome show that it causes a larger height error than the one-eighth inch dome, but not as large as the conical covers. These results are shown in figure 8. The L3 height solutions are plotted with red "+" symbols. The L3 height solutions with troposphere estimates are plotted with green "*" symbols. For the first solution, neither antenna had a dome on the antenna. For the last two days, one of the antennas had a one-quarter inch spherical dome mounted so that the mean phase center was centered with the cover. From this figure it appears as if the thicker one-quarter inch acrylic dome has a larger effect on the height solutions than the one-eighth inch dome. The L3 solutions with troposphere estimates are off by as much as 10 mm while the solutions without troposphere estimates are off by less than 5 mm.

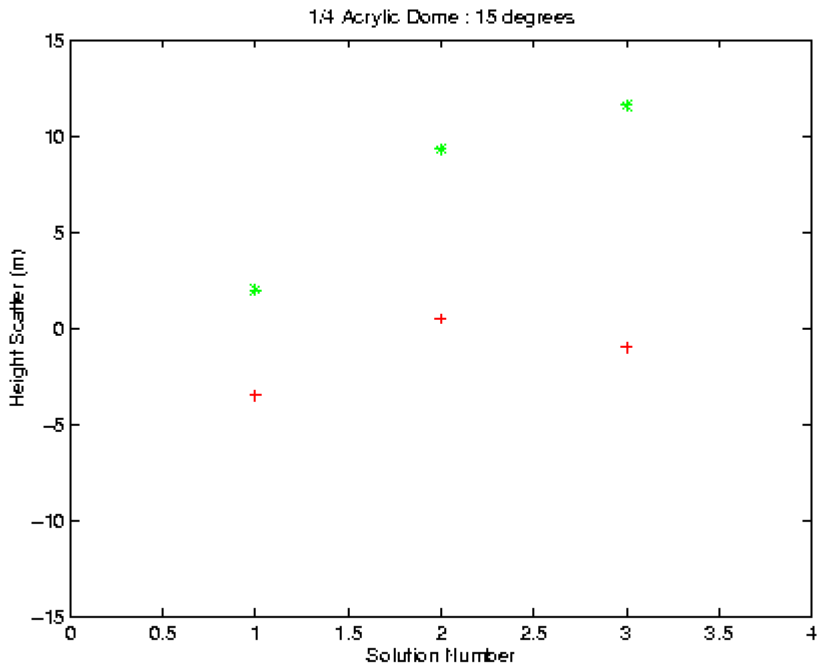

Figure 9: *Baseline height solutions for the one-quarter inch spherical acrylic cover. The solutions plotted here all use a 15 degree elevation cutoff for processing. The red "+" marks represent L3 height solutions without additional troposphere estimates. The green "*" marks represent the L3 height solutions with hourly troposphere parameters estimated. For the first solution, neither antenna was covered by a dome. For the second and third solutions, the one-quarter inch dome was covering one of the antennas. This data was taken on the UNAVCO facility roof and not at the TMGO. The ground truth for these marks is not as well known as the marks at TMGO.*

The effect of the various domes, and how the effect changes with the elevation cutoff angle used for data processing is summarized in Table 1. From this table, it can be seen that the conical covers have a larger effect on baseline height than the spherical covers. They also have a larger dependence on what elevation cutoff angle is being used for data processing.

Summary of Dome Effects on Height Solutions

Dome Type	**10 Degrees**	**15 Degrees**	**20 Degrees**
Ashtech Conical Dome	----	10 mm	21 mm
Trimble Conical Dome (w/ Choke Rings)	10	10	20
Trimble Conical Dome (w/ GEOD)	20	27	43

Concentric Spherical Dome (one-eighth inch)	2	2	2
Non Concentric Spherical Dome (one-eighth inch)	2	2	2
Spherical Dome (one-quarter inch)	----	10	----

Final UNAVCO Dome Design

From the results above, the one-quarter inch spherical dome cover can be seen to have the least effect on height solutions. UNAVCO used this information to construct a final UNAVCO dome that it will recommend to investigators. The final dome is shown below in figure10.

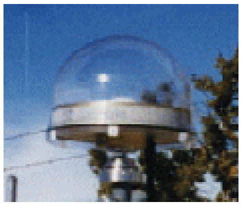

Figure 10: Picture of UNAVCO dome mounted on a Trimble Dorne Margolin choke ring antenna

This dome was tested, and its effect on the baseline height component solutions is less than 4 mm. The results are plotted in figure 11. Elevation cutoff angles of 10, 15, and 20 degrees are plotted in the top, middle, and bottom panels respectively. L3 solutions are plotted with the red "+" symbols, L3 solutions with additional troposphere parameters estimated are plotted with the green "*" symbols. The final UNAVCO dome was mounted over one of the antennas for days 344 and 345 only. Days 343 and 346 do not have a dome on either antenna. The solutions plotted in this figure show that the final UNAVCO dome causes less than a 4 mm error in the height component for processing elevation angles ranging from 10 to 20 degrees.

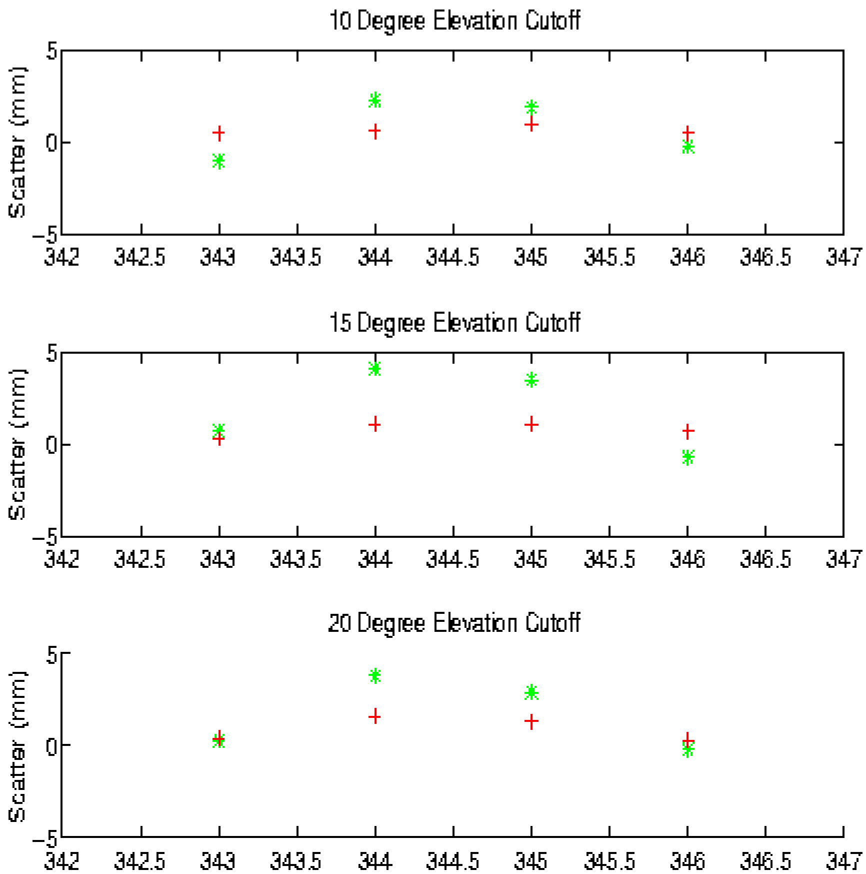

Figure 11: *Baseline height solutions for the final UNAVCO dome. The top panel has solutions plotted using a 10 degree elevation cutoff. The middle panel has solutions plotted using a 15 degree elevation cutoff. The bottom panel has solutions plotted using a 20 degree elevation cutoff. In all panels, the red "+" marks represent L3 height solutions. The green "*" marks represent the L3 height solutions with additional hourly troposphere parameters estimated. The final UNAVCO dome was placed on one of the antennas on days 344 and 345. Days 343 and 346 do not have a dome on either antenna.*

Conclusions

Clearly, the addition of a cover over an antenna causes an error to be introduced into the height component of baseline solutions. The magnitude of the error depends on the shape of the cover, the thickness of the cover, how it is mounted around the antenna, and what type of material is used to construct the cover. The conical shape of both the Ashtech and Trimble covers appears to produce the most severe effects (figs 5 and 7). The Trimble conical cover produced errors as large as 44 mm for L3 height solutions with troposphere parameters estimated at one of the sites. The spherical antenna covers produce a much smaller error than the conical covers. For all spherical covers, the errors are all less than 10 mm and as small as 2 mm.

With the spherically shaped antenna covers, the thickness and mounting of the covers can cause variations in the height solutions (figs. 8 and 9). Errors as large as 10 mm are seen when a one-quarter inch dome is mounted so that the antenna's mean phase center is not located in the center of the dome. If a one-eighth inch dome is mounted so that the phase center of the antenna was in the center of the cover, the error drops to 4 mm or less. Both error bounds above are for solutions with troposphere parameters estimated at one of the sites. Generally, the noise of an L3 height solution with troposphere parameters estimated at one site is about 2 mm. The horizontal components of the baseline solutions do not noticeably change for these solutions, but results in Scandinavia show that there is up to a 10 mm change in horizontal baseline components with and without antenna covers (Jim Davis, personal communication).

The magnitude of the errors is also a function of the elevation cutoff angle used for processing (fig. 5). L3 height solutions using the Trimble conical dome, and with troposphere parameters estimated, vary by more than 30 mm between 10 and 20 degrees elevation cutoff. Differences in solutions that vary as a function of elevation cutoff angle, and differences in height solutions with and without troposphere parameters estimated implies that antenna covers cause errors that are mismodeled as tropospheric delay. This is important to scientists who use GPS to accurately monitor atmospheric water vapor.

In addition to the antenna covers, the metal mounting plate of the Trimble conical cover appears to cause a baseline height error as well. Both the Trimble Dorne Margolin choke ring antenna and the Trimble L1/L2 GEOD GP antenna are affected by this large mounting plate (figs. 5 and 6). The mounting plate causes the largest signal when it is attached under an antenna like the Trimble L1/L2 GEOD GP (i.e. one that uses a ground plane to suppress multipath instead of choke rings).

As is the case with many errors in very high precision GPS surveying, it is possible for the effect of domes to cancel out at the single difference level. For very short baselines with two antennas using the same cover type, a common error is introduced to both stations which is subtracted out when the single difference observation is formed. However as baseline length increases, and the two antennas observe a satellite at different azimuth and elevation angles, the errors no longer cancel at the single difference level. It is also likely that the observations from one station will be processed with data taken from another station with a different type of antenna cover, or no cover at all. In these examples the effects will not difference out, and an error will be introduced.

Ideally, it would be best if no cover were needed over an antenna. However, some permanent GPS sites require their use to keep rain, snow and animals away. In this instance it appears that the best solution is one where the cover is thin, nearly spherical in shape, and mounted so that the radius of curvature is centered near the mean electronic phase center of the antenna. While still producing an error in the vertical baseline component, the effect is minimized.

Bibliography

Braun, J., C. Rocken, B. Stephens, W. Shiver, M. Exner, O. Ruud, C. Conquest, J. Johnson, and C. Meertens; "Results of 1995 UNAVCO ARI Equipment Tests"; Trans. Amer. Geophys. Un. Vol 76, pg F147: November 7, 1995

Elosegui, P., J. L. Davis, R. T. K. Jaldehag, J. M. Johansson, A. E. Niell, I. I. Shapiro; "Geodesy Using the Global Positioning System: The effects of signal scattering on estimates of baseline length"; Radio Science, Vol 20, 1593-1607; 1985

Niell, A.; "Near-field Problems for GPS Antennas";

Rocken, C., C. Meertens, B. Stephens, J. Braun, T. VanHove, S. Perry, O. Ruud, M. McCallum, J. Richardson; "UNAVCO Academic Research Infrastructure (ARI) Receiver and Antenna Test Report"; UNAVCO Memo; November 1995