

Assessing the Impact of the SCIGN Radome on Geodetic Parameter Estimates

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Introduction

The SCIGN radome is widely used within the geodetic community to protect GPS antennas at permanent sites from snow, debris accumulation, and vandalism. It was designed to have uniform thickness, minimizing its impact on the electrical phase center of the associated antenna. Dragert and Schmidt in their paper “The Effect of SCIGN Domes on the Vertical Phase Centre Position in Routine Processing of GPS Data” found that the radome altered the vertical coordinate solutions by 1.5 cm when used with a Dorne-Margolin(DM)/JPL Choking antenna. This report suggested that this coordinate change was induced by a misalignment of the radome center of curvature with the mean L1/L2 electrical phase center. Ken Hudnut (the designer of the radome) confirmed this misalignment noting that the radome was designed to have a radius of curvature centered at the physical center of the DM element. There is a 3.5 cm difference between the physical position of the element and the electrical phase center; the electrical phase center is higher. Gerry Mader at the National Geodetic Survey (NGS) suggested that the NGS phase center variations (PCV) for the antenna and radome configuration should properly model this misalignment, and the radome should have no impact on geodetic parameter estimates. Dragert argues, that the empirical PCV determination technique used by the NGS does not estimate tropospheric delay parameters, inducing an error when these parameters are included in the data analysis. This report summarizes a detailed analysis of data collected at the Piñon Flat Observatory specifically collected to quantify what impact the SCIGN radomes have on geodetic parameter estimates.

Experiment Description

There are two continuous GPS sites, PIN1 and PIN2, at the Piñon Flat Observatory. These two monuments are separated by approximately 50 meters and are maintained by researchers Frank Wyatt and Duncan Agnew at the Scripps Institution of Oceanography in San Diego, California. These two sites were used in December 1998 to evaluate what impact the tall SCIGN radome (SCIT) had on station coordinate solutions. Logistical details of these tests are available from the field Pinon Flat Observatory field log¹. In summary a SCIT radome was periodically installed and then removed from the GPS antenna at the PIN2 monument. A schematic diagram of the PIN2 antenna/radome

¹ Frank K. Wyatt and Duncan Carr Agnew. The PIN1 and PIN2 GPS Sites at Pinon Flat Observatory. February 4, 2005. Scripps Institution of Oceanography Technical Report. <http://repositories.cdlib.org/sio/techreport/33>

configuration is shown in Figure 1. It was assumed that the routine vertical coordinate solutions computed for the PIN2 station would capture any significant change in this stations height coordinate. This report summarizes an additional analysis of data from both PIN1 and PIN2 stations as well as three other SCIGN stations in the southern California region and finally three IGS reference sites in North America. The list of stations used in the analysis, their antenna types, radome types, and antenna heights are shown in Table 1. Pictures of the antenna types used here are shown in Figure 2. In 1998, the conical SNOW radome was still being deployed and used. Two stations in this analysis (MONP and WIDC) were equipped with this SNOW radome. The results presented here can also be used to quantify how this cover affects geodetic parameter estimates too.

PIN2 ANTENNA STATUS

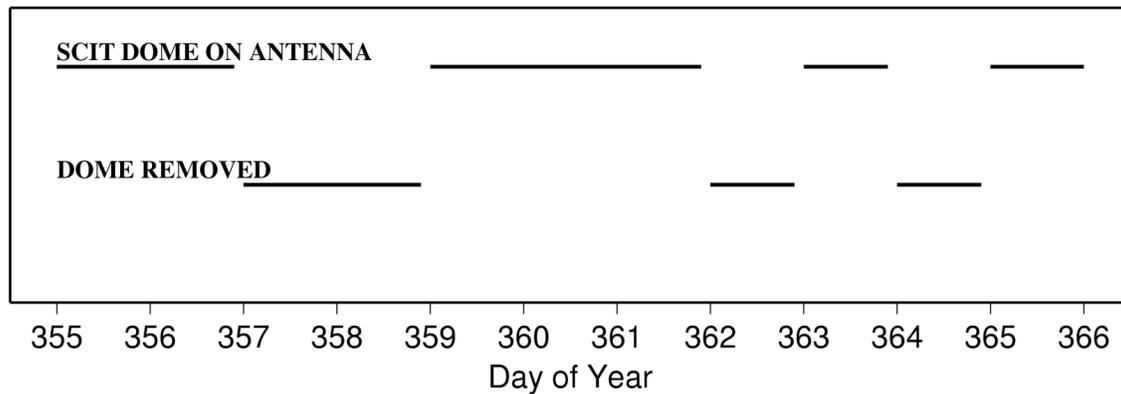


Figure 1: Antenna/radome configuration at station PIN2. This information is taken from the Wyatt and Agnew enhanced logbook.

Table 1: Stations used in SCIGN Dome Testing. The antenna, dome, and antenna height information was taken from IGS log sheets².

Station	Antenna	Radome	Antenna Height
GOLD	AOAD/M T	NONE	0.0254
MDO1	AOAD/M T	JPLA	0.061
PIE1	AOAD/M T	JPLA	0.061
MONP	ASH700936B M	SNOW	0.1186
PIN1	AOAD/M TA NGS	NONE	1.845
PIN2	ASH700936E C	SCIT/NONE	0.0083
PPBF	ASH700936E C	NONE	0.0083
WIDC	ASH700936D M	SNOW	0.0083

² ftp://garner.ucsd.edu/pub/docs/site_logs and <ftp://igscb.jpl.nasa.gov/igscb/station/log>



Figure 2: Antennas used in this experiment. All figures downloaded from the NGS phase center calibration page³.

Data Analysis

All data were processed using the Bernese V4.2 software. The International GPS Service (IGS) final orbits were used. These orbits were published in an ITRF97 reference frame. The a priori station coordinates for sites were computed through a routine network analysis using the IGS stations PIE1, GOLD, and MDO1. These sites were constrained to their published IGSb00 values and used to estimate the coordinates for the remaining stations (PIN2, PIN1, PPBF, WIDC, and MONP). The mixing of orbits in an ITRF97 and constraining station coordinates to their published IGSb00 values should have no significant impact on this analysis.

The modifications to the PIN2 antenna were all made between the hours of 2300UTC and 0100UTC. The data files in this test were therefore windowed to create sessions beginning at 0100UTC and ending at 2300UTC for each day. Session lengths are therefore 22 hours.

The antenna and radome testing was conducted through individual baseline analysis. A “STAR” strategy was implemented, with baselines being formed from station PIN2 to all other stations in the network. The PIN2 coordinate for each of these baselines was estimated, holding the other station coordinate fixed to the a priori value obtained from the previous network analysis. The baselines to PIN1, PPBF, WIDC, and MONP all had lengths less than 85km. These short lengths do not allow for absolute troposphere delay retrieval, so relative parameters were estimated only at station PIN2.

³ <http://www.ngs.noaa.gov/ANTCAL>

Baselines were processed with two different antenna phase center files. The first strategy used the horizontal and vertical phase center values only, no elevation dependent corrections were applied. These results are called NO_PCV within the results below. The second strategy used the horizontal and vertical phase center values, and included the elevation dependent patterns associated with each antenna. These results are called the PCV within the results below.

Relative Antenna PCV Information

The antenna phase center information was taken directly from the NOAA antenna phase center calibration page (<http://www.ngs.noaa.gov/ANTCAL/index.shtml>). There are two comments on how these PCV models were used. First, all elevation dependent PCV information was rounded to the nearest integer millimeter. This was done to comply with the input format of the Bernese 4.2 file. Second, there is no official PCV model for the ASH700936E_C+SCIT combination of antenna and dome (or any ASH700936 antenna types). In replacement, the ASH701945B_M+SCIT PCV model was used. The ASH701945B_M uses a D/M element with milled chokerings, and should have a similar PCV as the other Ashtech antennas with these characteristics. A comparison of ASH701945 and ASH70936 patterns shows PCV differences of less than 2 mm for the ionosphere free “L3” linear combination. Horizontal and vertical antenna phase center information for all antenna types used are given in Table 2. The elevation dependent PCV models for all antenna types used are shown in Figure 3. For the ionosphere free “L3” linear combination, the magnitude of the PCV correction can be as large as 4 mm for the SCIT dome (and ~5 mm) for the SNOW dome. Neither of these PCV models would indicate that the SCIT dome would induce a 1.5 cm vertical coordinate error.

Table 2: Antenna phase center offsets for all antenna types used in this analysis.

Antenna Type	Frequency	North (mm)	East(mm)	Up (m)
AOAD/M_T	L1	0.0 mm	0.0 mm	0.1100 m
	L2	0.0	0.0	0.1280
AOAD/M_TA_NGS	L1	0.0	0.0	0.1100
	L2	0.0	0.0	0.1280
ASH700936B_M SNOW	L1	0.3	-0.2	0.1081
	L2	0.9	0.5	0.1256
ASH700936D_M	L1	0.2	-0.1	0.1097
	L2	0.3	1.0	0.1277
ASH700936D_M SNOW	L1	0.3	-0.2	0.1081
	L2	0.9	0.5	0.1256
ASH700936E_C	L1	1.4	-1.0	0.1089
	L2	1.0	0.5	0.1274
ASH700936E_C SCIT (ASH701945B_M SCIT)	L1	0.1	0.1	0.1074
	L2	-0.1	0.2	0.1255

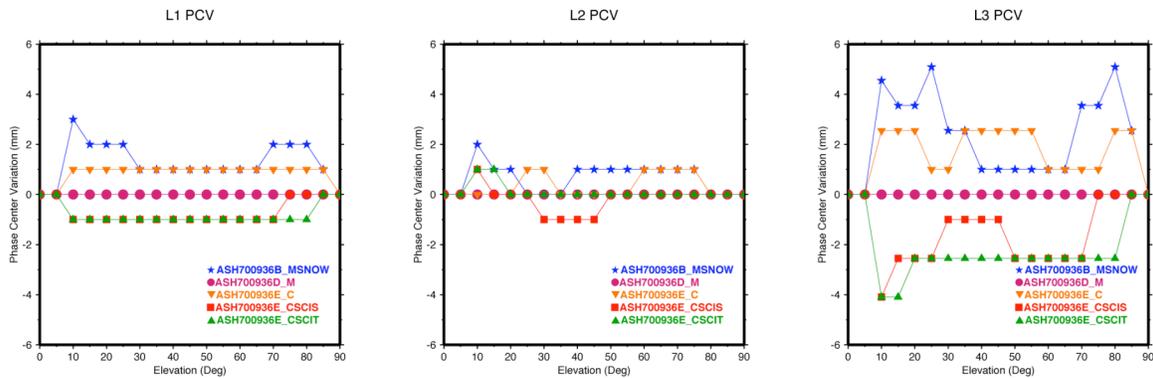


Figure 3: Elevation dependent phase center corrections for antenna types used in this experiment. PCV values are rounded to the nearest integer millimeter from the NOAA/NGS (<http://www.ngs.noaa.gov/ANTCAL/index.shtml>).

Antenna radomes alter the phase center variation of all antennas. The magnitude of these PCV changes governs the magnitude of the how large an effect they may have on coordinate and troposphere estimates. Figure 4 plots the PCV corrections of the SCIGN short (SCIS) and SCIGN tall (SCIT) radomes for all unique antenna types. PCV corrections for the SCIS antenna are only available for Ashtech and Trimble DM-choking type antennas. There are PCV corrections for both Ashtech and Trimble DM-choking antennas as well as two other Trimble ground-plane antennas. The maximum correction for the DM-choking type antennas is ~6mm in L3 PCV. The SCIS and the SCIT radomes were designed to keep the same radius of curvature relative to physical center of the top of the DM-choking. This constraint should create a radome PCV model that is identical for the SCIS and SCIT. The differences in Figure 3 indicate that the radius of curvature is slightly different for the two types of radomes. Additionally, the large elevation dependent PCV corrections for the two Trimble antennas with ground planes is an illustration of how sensitive the PCV model is to radome type covers.

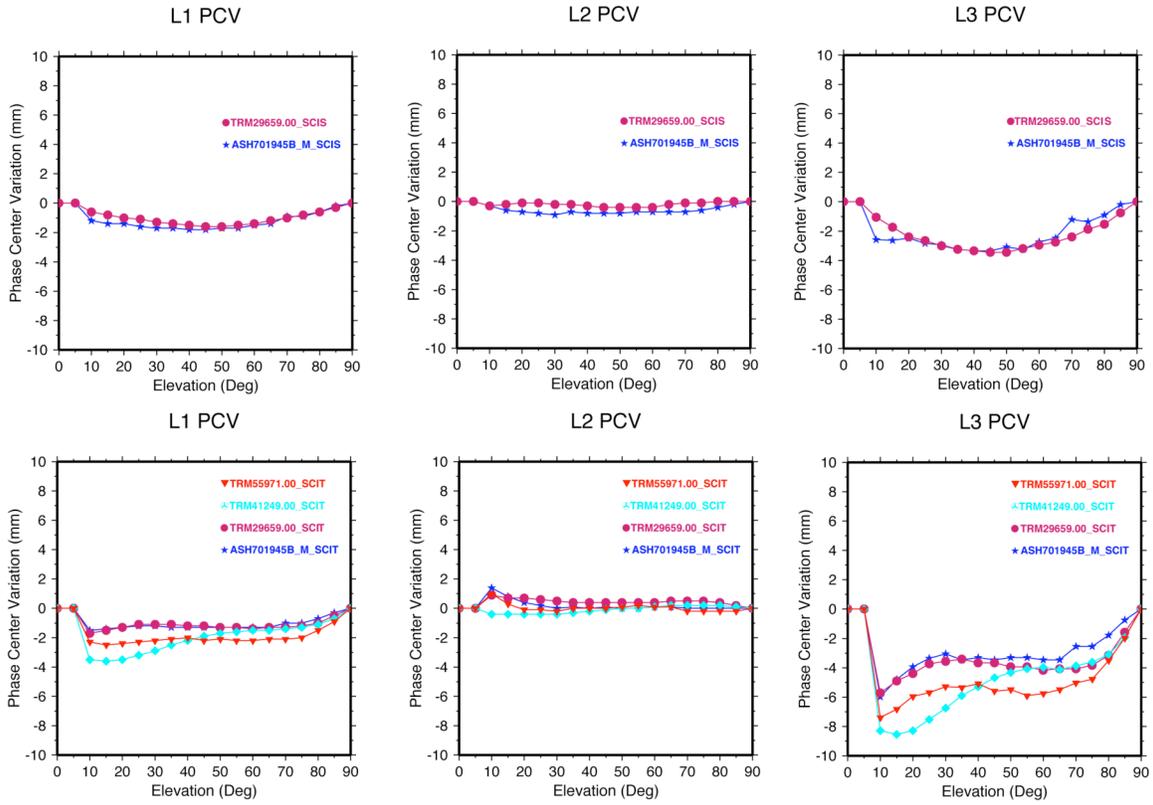


Figure 4: Elevation dependent phase center corrections for SCIS (top) and SCIT (bottom) radome types. These are the PCV corrections of only the radome, the PCV correction of the antenna has been subtracted. The TRM1249.00_SCIT (cyan) and TRM55971.00_SCIT (red) are groundplane types of antennas, not chokerings types.

Results and Analysis

The results of the analysis are summarized below. In general the coordinate solutions were reasonable, with horizontal repeatabilities on the order of a few millimeters, and vertical repeatabilities less than a centimeter for baseline lengths less than 250 km (when evaluating results using the same elevation mask and elevation dependent PCV model). Results are presented beginning with the shortest baseline between stations PIN2 and PIN1 and extending in length. The single frequency solutions for the short baseline between PIN2 and PIN1 are not shown in this report, because they do not reveal any additional details that are not evident from the L3 solutions. Single frequency results for longer baselines are corrupted by unmodeled ionospheric errors and are not considered.

Tropospheric parameter estimates are presented by considering differences in solutions when elevation dependent PCV maps are, and are not applied. The average daily difference in troposphere estimates for solutions with the PCV model and without the PCV model are calculated and shown for each baseline. This average difference shows the impact of the PCV model, not necessarily the radome. Dragert and Schmidt reported a significant change in estimated station height when the SCIT radome was installed. A change in the vertical coordinate of 1.5 cm should correspond to a change in tropospheric parameter estimates of ~ 5 mm. For short baselines, a 5 mm change in zenith delay may be detectable. For longer baselines, a 5 mm change in 30-minute tropospheric delay is within the standard stochastic behavior of the atmosphere.

Vertical coordinate results are also presented for each baseline. Recall that the coordinate of station PIN2 was estimated for each baseline, with the other station coordinates being held fixed to a previously computed coordinate from a network analysis of all stations.

The results presented use similar symbols to represent a particular elevation mask, and a color to represent if the elevation dependent PCV model has been applied. A summary of all symbols and color-coding of results is shown in Figure 5.

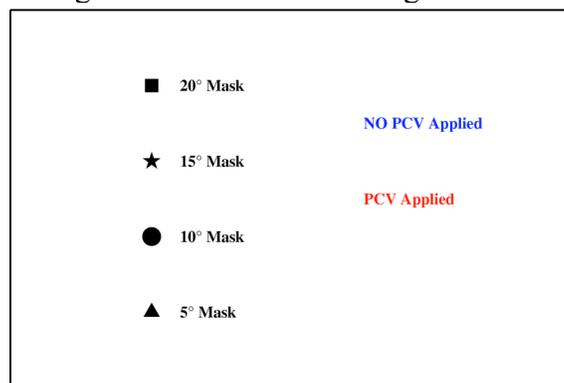


Figure 5: Summary of symbols and colors used in remaining figures.

Baseline PIN2 to PIN1

The baseline between PIN2 and PIN1 is approximately 50 meters. The antenna combination is the ASH700936E_C (SCIT) – AOAD/M_TA_NGS (Figure 6). The following observations can be made from the results of this short baseline.

- When considering results with similar elevation masks, there is almost no difference in troposphere estimates (when evaluating individual estimates, or daily averages) when the elevation dependent PCV models are applied (red) or not (blue) (Figure 7). There is a small bias (~2mm) for solutions using an elevation mask of 20 when the SCIT radome is not on the PIN2 antenna (days 357, 358, 362, and 364).
- The estimated station coordinates are nearly identical for solutions with similar elevation mask, regardless of whether the PCV model was applied (Figure 8).
- There is no significant change in the height solutions when the SCIT radome is installed.
- There is a relatively strong dependence in troposphere estimates (Figure 7, bottom panel) and station coordinates as a function of elevation mask (Figure 8).



Figure 6: Antenna models used in the 50 meter baseline between PIN2 and PIN1.

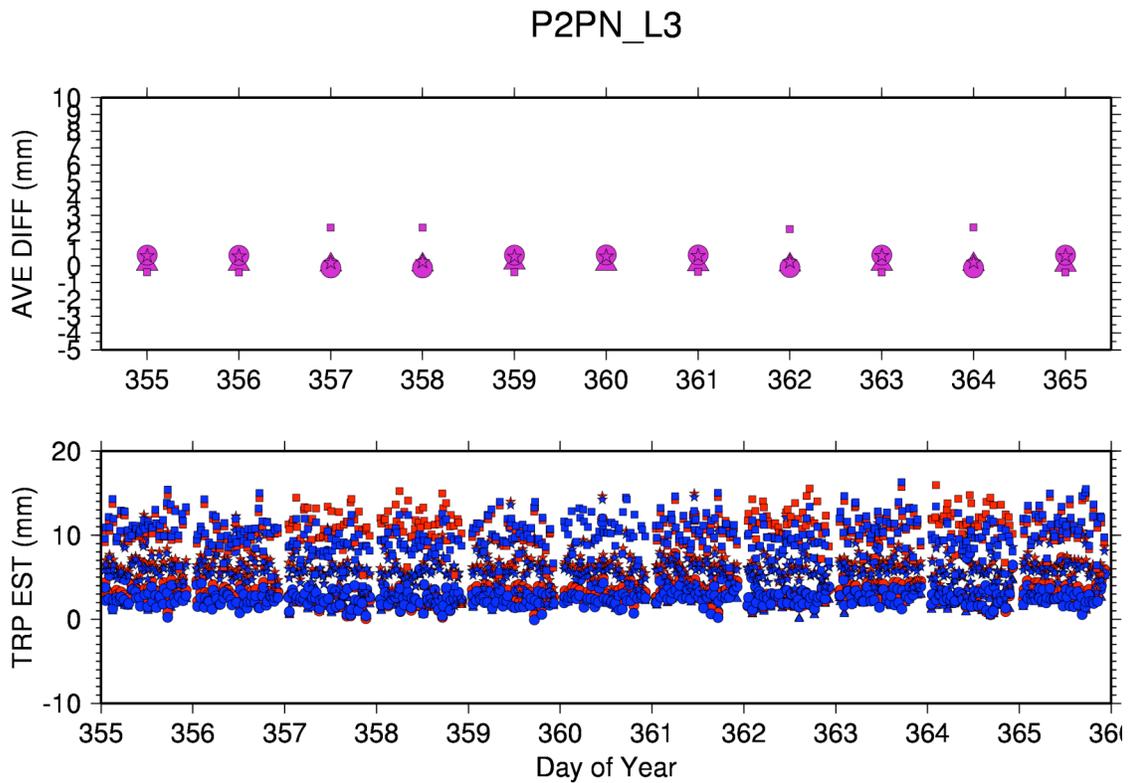


Figure 7: Relative troposphere estimates for the PIN2-PIN1 baseline (bottom). The average difference between relative troposphere estimates with and without elevation dependent PCV modeling (top).

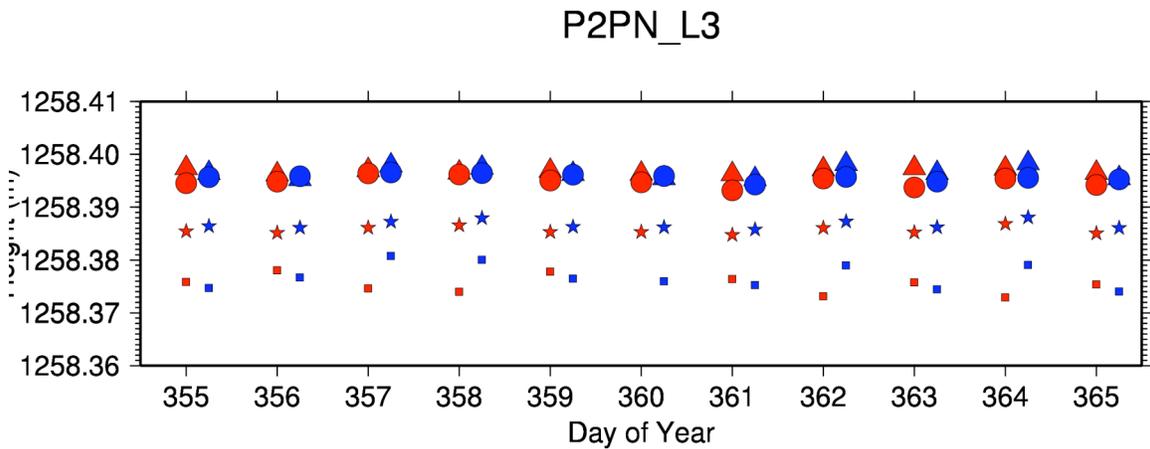


Figure 8: Coordinate height solutions for station PIN2 relative to station PIN1. The results that are shown include solutions with elevation masks of 5, 10, 15 and 20; with and without elevation dependent PCV maps applied.

Baseline PIN2 – PPBF

The baseline between PIN2 and PPBF is a baseline of approximately 72 km in length. Both antennas use the ASH700936E_C antenna (Figure 9). This baseline allows for the most direct test of the SCIT radome at PIN2. The following observations can be made from these results.

- The two antennas appear to have nearly identical antenna PCV patterns, as can be seen for the solutions without a radome (357, 358, 362 and 364). For two antennas of the same type and model, this is expected. For this short baseline, with antennas of the same type, the elevation dependent PCV corrections had little or no impact on the solutions.
- The radome has no noticeable impact on either the troposphere (Figure 10) or coordinate (Figure 11) solutions for elevation masks of 5, 10, and 15.
- There is slight elevation dependence (~3 mm at 20) in the troposphere estimates between the solutions using the PCV and not using the PCV when the SCIT dome is on PIN2. (355,356,359-361, 363, and 365).
- The scatter in the height solutions across all elevation masks is improved when using the PCV corrections for “dome on” days (355, 356, 359, 360, 361, 363, and 365).
- Based on differences in troposphere estimates and station height coordinates, the impact of the radome appears to be within the daily scatter of the solutions.



Figure 9: Antenna models used in the 72 km baseline between PIN2 and PPBF. This baseline is the only one in the test where the antenna model was the same at both stations.

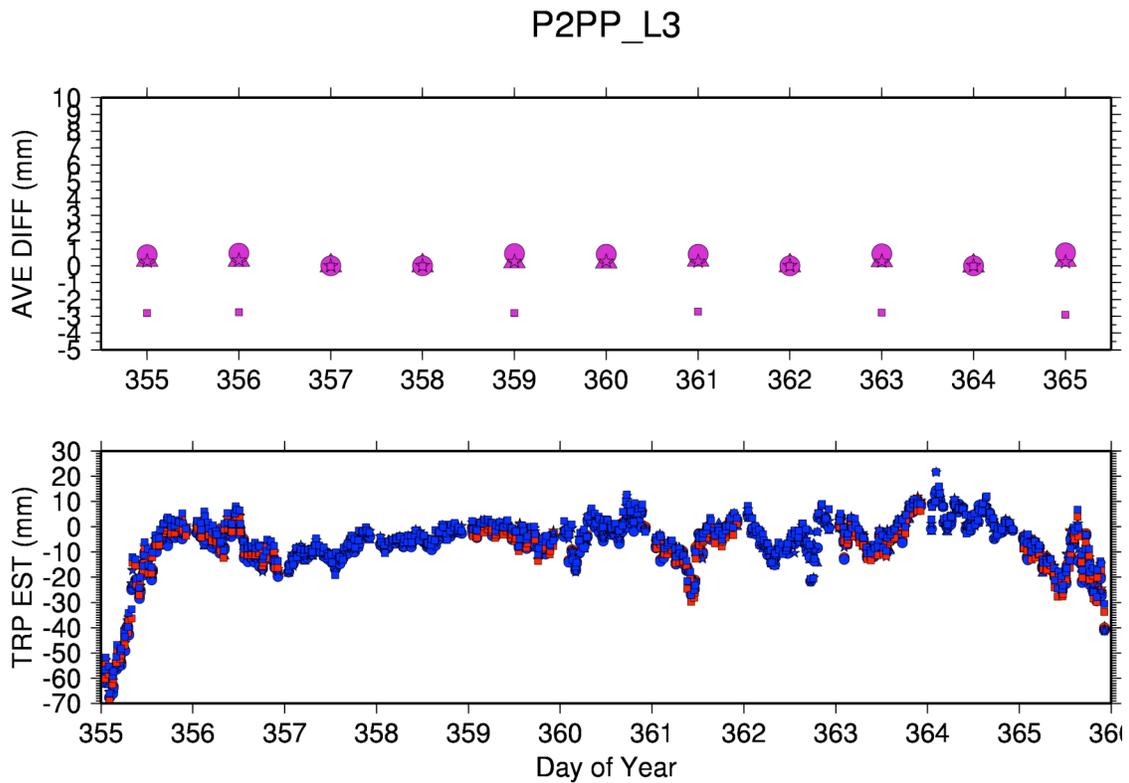


Figure 10: Relative troposphere estimates for the PIN2-PPBF baseline (bottom). The average difference between relative troposphere estimates with and without elevation dependent PCV modeling (top).

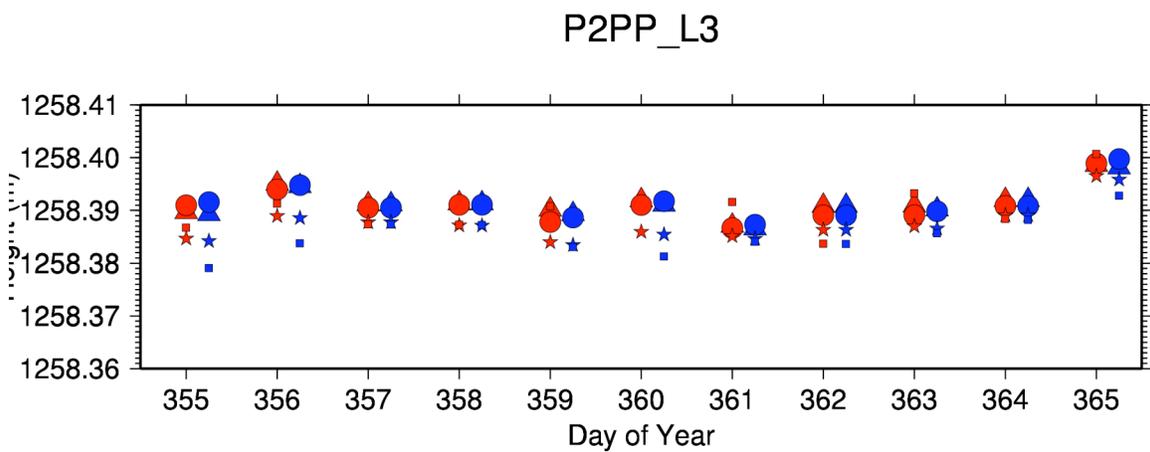


Figure 11: Height coordinate solutions for the 72 km baseline between PIN2 and PPBF. The radome is removed for sessions 357, 358, 362, and 364.

Baseline PIN2 - MONP

This baseline is approximately 80km in length. The antenna combination is ASH700936E_C(SCIT) - ASH700936B_M SNOW (Figure 12). The following conclusions can be made using the results from this baseline:

- The SNOW radome has a major impact on the differences in troposphere estimates (Figure 13). This is especially true for solutions with the 20 mask, where there is a 6-8 mm differential ZTD difference between solutions that use the PCV corrections and those that do not.
- When comparing the troposphere estimates with and without PCV maps applied, the mean troposphere difference increases for days when the SCIT dome is removed from station PIN2. This increase is most likely explained by the fact that the SNOW and SCIT radomes have PCV corrections that are of opposite sign that difference away when both radomes are installed.
- For solutions using 5 and 10 elevation mask, there is no clear difference in either the troposphere estimates or station coordinates (Figure 14) when the PCV model is applied.
- The SCIT radome has no noticeable affect on the parameter estimates for this baseline.



Figure 12: Antenna models used in the 80 km baseline between PIN2 and MONP.

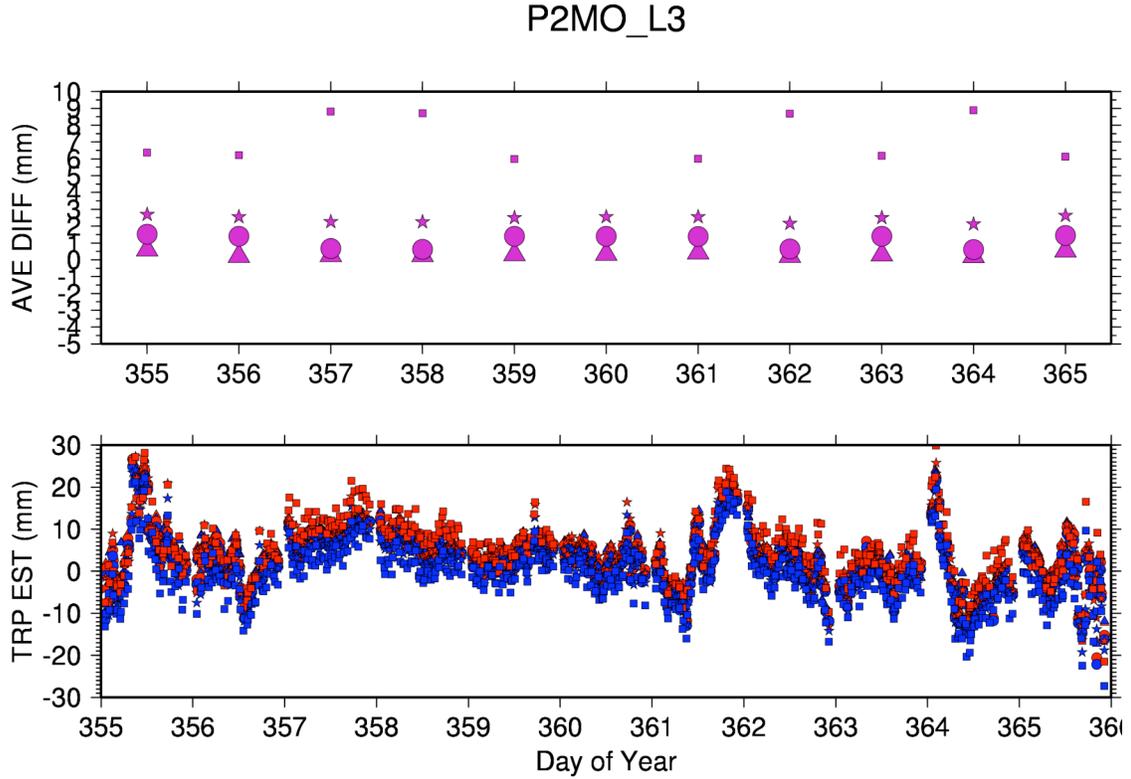


Figure 13: Relative troposphere estimates for the PIN2-MONP baseline (bottom). The average difference between relative troposphere estimates with and without elevation dependent PCV modeling (top).

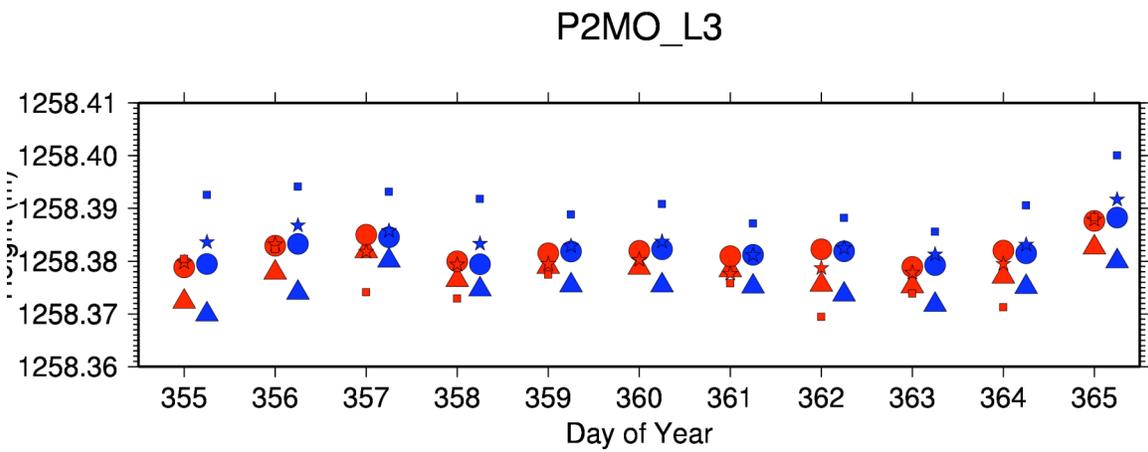


Figure 14: Height coordinate solutions for the 80km baseline between PIN2 and MONP. The radome was removed for sessions 357, 358, 362, and 364.

Baseline PIN2 to WIDC

This baseline is approximately 32 km in length. The antenna combination is ASH700936E_C(SCIT) - ASH700936B_M SNOW (Figure 15), which is similar to the PIN2-MONP baseline. There are no significant differences between results for this baseline and the PIN2-MONP baseline. The following conclusions can be made using the results from this baseline:

- The SNOW radome has a major impact on the differences in troposphere estimates (Figure 16). This is especially true for solutions with the 20 mask, where there is a 6-8 mm differential ZTD difference between solutions that use the PCV corrections and those that do not.
- When comparing the troposphere estimates with and without PCV maps applied, the mean troposphere difference increases for days when the SCIT dome is removed from station PIN2. This increase is most likely explained by the fact that the SNOW and SCIT radomes have PCV corrections that are of opposite sign that difference away when both radomes are installed.
- For solutions using 5 and 10 elevation mask, there is no clear difference in either the troposphere estimates or station coordinates (Figure 17) when the PCV model is applied.
- The SCIT radome has no noticeable affect on the parameter estimates for this baseline.



Figure 15: Antenna models used in the 32 km baseline between PIN2 and WIDC.

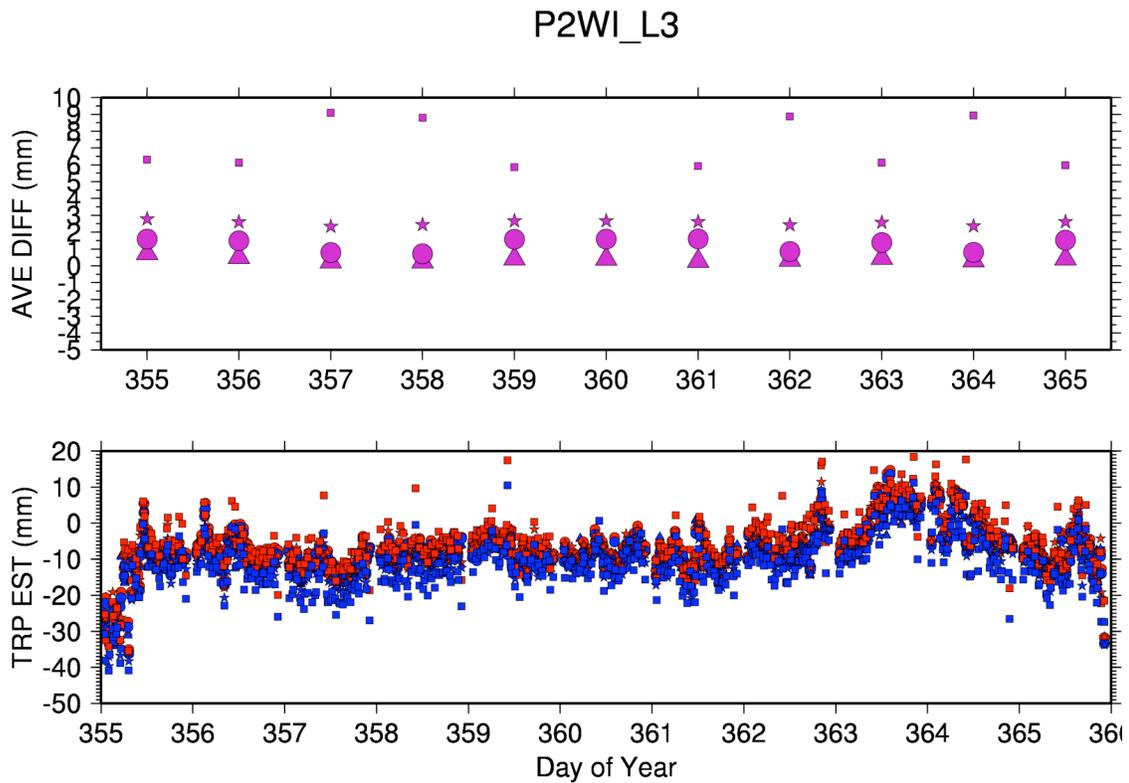


Figure 16: Relative troposphere estimates for the PIN2-WIDC baseline (bottom). The average difference between relative troposphere estimates with and without elevation dependent PCV modeling (top).

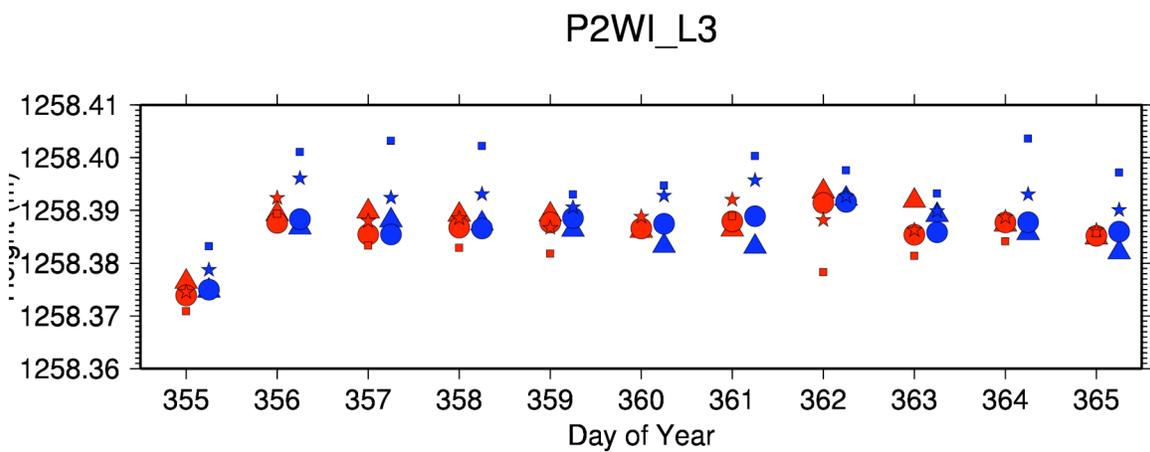


Figure 17: Height coordinate solutions for the 32 km baseline between PIN2 and WIDC. The radome is removed for sessions 357, 358, 362, and 364.

Baseline PIN2 to GOLD

This baseline is approximately 205 km in length. The antenna combination is ASH700936E_C (SCIT) - AOAD/M_T (shown in Figure 18). For relative antenna PCV models, the standard AOAD/M_T antenna does not have any elevation dependent PCV corrections. The following comments can be made about results from this baseline:

- An analysis of the GOLD observation files using QC indicates that the GPS receiver at this site was tracking approximately 60% of all visible satellites during this time period. These tracking problems produced solutions that used approximately half the number of double difference observations. The results from this baseline should be viewed with some skepticism.
- There are clear biases of approximately 4 mm in troposphere estimates for all elevation masks for days when the radome is removed from the PIN2 antenna (days 357, 358, 362, and 363). The 4 mm difference in troposphere estimates translates into a ~1 cm difference in station height (Figure 20). This indicates that the PCV model for the ASH700936E_C without any radome cover is significantly different than the AOAD/M_T antenna.
- There is very little elevation dependence in either the troposphere or station height estimates.
- The solutions with the smallest coordinate scatter are those derived without using PCV corrections (Figure 20).
- The near-zero biases in troposphere estimates, and the station coordinate solutions for days when the radome is on the PIN2 antenna, indicate that the radome has no significant impact on parameter estimates.

ASH700936E_C



AOAD/M_T



ASH701945B_M+SCIT



Figure 18: Antenna models used in the 205 km baseline between PIN2 and GOLD.

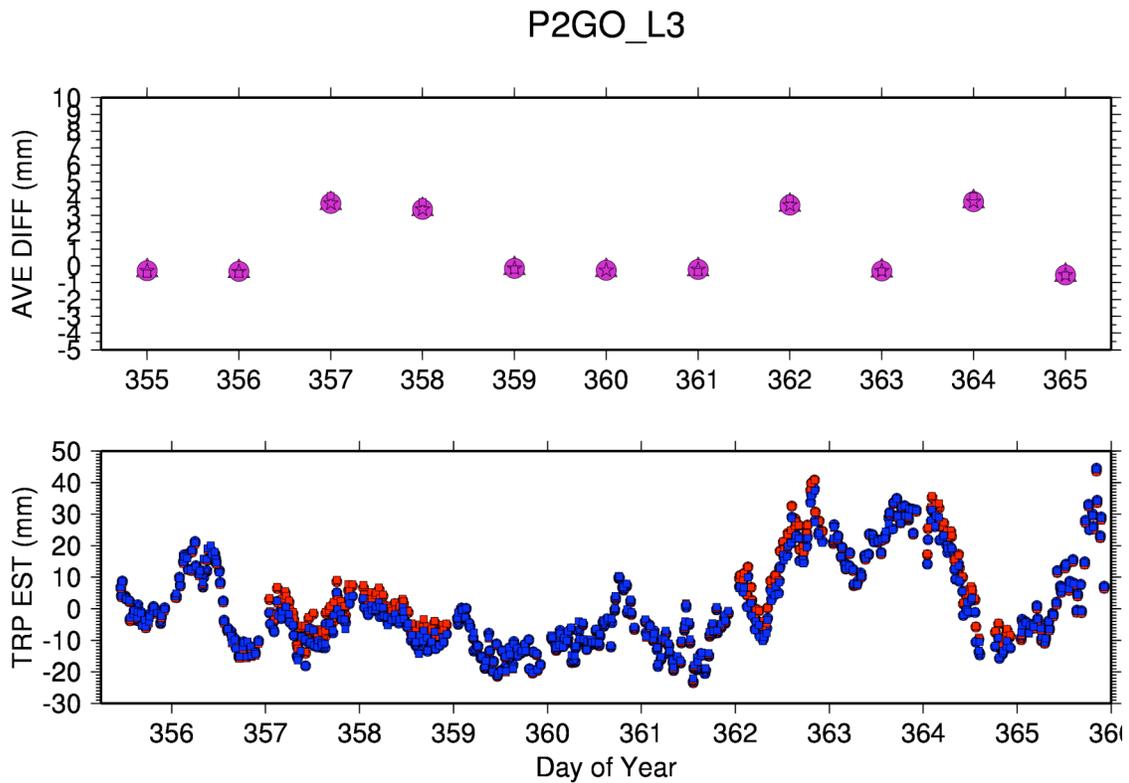


Figure 19: Relative troposphere estimates for the PIN2-PIN1 baseline (bottom). The average difference between relative troposphere estimates with and without elevation dependent PCV modeling (top).

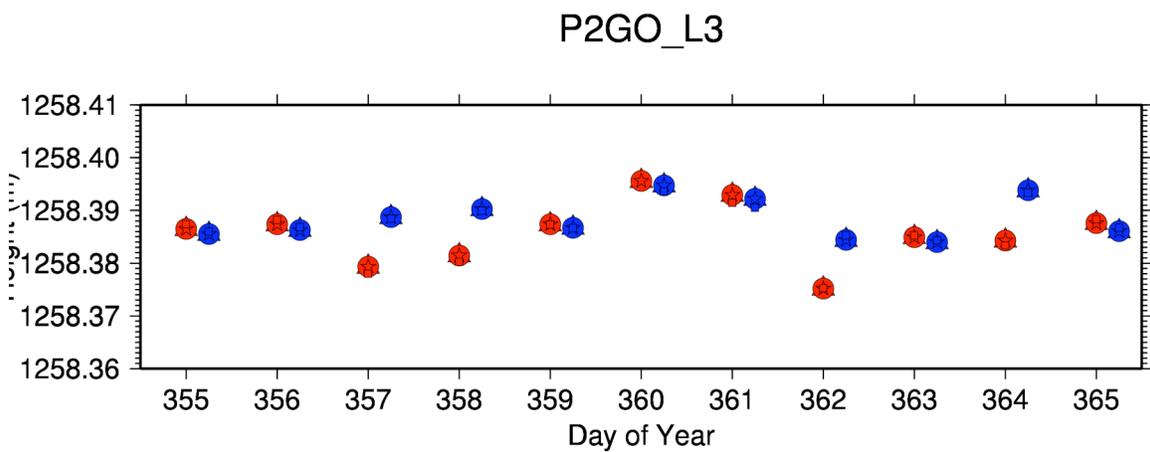


Figure 20: Height coordinate solutions for the 205 km baseline between PIN2 and GOLD. The radome is removed for sessions 357, 358, 362, and 364.

General Conclusions

The analysis of data from the SCIGN radome testing at Piñon Flat Observatory showed no noticeable impact in either station coordinate or troposphere parameter estimates when the SCIT radome was installed at station PIN2. This is in disagreement with those results previously presented by Dragert and Schmidt. When solutions using a constant elevation mask were considered, the repeatability of station height coordinates was on the order of 1 cm or less. There were no significant changes in station height for days when the SCIT radome was installed at PIN2. For elevation masks of 5 and 10, the elevation dependent PCV maps published by the NGS produced almost no change in either the troposphere or coordinate solutions. The one exception was the baseline between PIN2 and GOLD where there were differences in coordinate height of ~1cm for solutions when there was no radome on the PIN2 station. As mentioned earlier, the receiver at GOLD recorded approximately 60% of all possible data. This makes the solutions for this baseline less reliable than the other baselines.