THE IMPACT OF RADOME ON THE GPS OBSERVATION

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Abstract

The GPS antenna detects an electromagnetic signal arriving from a satellite, doing filtering, and finally going through further processing by the receiver electronics. For geodetic, high-precision applications such as for continuous monitoring, additional ground plane or choke rings have been used primarily to mitigate multipath effects. In addition, GPS antennas for such applications are often protected against possible damages by a plastic housing (radome), designed to minimize attenuation of the signal. This paper discusses the use of radome and field test results on the effect of using radome on the performance of GPS observations. This serves as the background for the implementation of radome on ground reference station antenna especially in countries such as Malaysia, which experienced high humidity and abundant rainfall. Several GPS measurements have been made by simulating the environment for example by spraying the water when the antenna is covered with or without hemisphere radome made of fibre glass. Finally, this paper will show the results of some case studies that have been performed.

Keywords: *GPS, Antenna, Radome, Quality*

1.0 INTRODUCTION

The Global Positioning System, (GPS) has become a widely used tool for many applications such as geodesy, geodynamic, and engineering survey. The high precision and accuracy achieved by GPS positioning has seen the establishment in many countries of permanent GPS reference stations such as the MASS stations of the Department of Surveying and Mapping (JUPEM), Malaysia. Reference stations are mainly used in GPS positioning for the following three purposes (Ogonda, 2003);

- Harmonization of the different geodetic reference systems around the world and more specifically, transforming the WGS84 reference system to user defined ellipsoid/datum, such as Geodetic Datum of Malaysia 2000.
- Detection of malfunctioning and failure of other reference stations
- Attenuation of the satellite, receiver and signal propagation biases.

To protect the antennas from bad weather, vandalism and prevention of long term antenna damage, reference station antennas are usually covered by radomes. LEICA System 500's antennas were equipped with a safety device, or radome. Normally there are two kind of radome in used, i.e. the conical and spherical shape. As mentioned earlier, radome is used to enclose antenna with the principal purpose of shielding the antennas of permanent reference GPS stations from the physical environment likes hot, wet, and strong wind, acid rain and ultra violet. Signal come from satellites are easier to reflect when approach to the solid and slippery surface like radome. Many studies have been done in this area, in order to analyse accurately and improve the performance of the radome (for example Ogonda (2003), Kaniuth & Stuber (2002) and Hudnut (1998))

In this paper, various combinations of LEICA System 500 antennas either with or without radome were tested by performing baseline measurement. Tests were performed in different condition and the analysis for each situation was presented. For the purpose of the study, two stations have been established and investigations on the effect of conical radome on one of the stations were carried out.

2.0 PROBLEM STATEMENT

The different design, size, and material of the radome will influenced the received signal and gave the different kind of error. The main function of a radome is to protect an antenna and it should appear transparent to radio frequency so as not to degrade the electrical performance of the enclosed antenna. However, in practice, radome effects on its radiation pattern can alter the antenna performance. The more significant of these effects is the bore sight error that is the bending of the angle of arrival of a received signal relative to its actual angle of arrival, arising from distortions of the electromagnetic wave front as it propagates through a dielectric radome wall. Another effect is antenna side lobe level degradation which occurs both because of losses in the radome and distortion in. the antenna pattern. In addition, radiation scattered from the radome surface may affect radar performance by elevating antenna side lobes. The loss of transmission is usually the result of reflection at the air/dielectric interfaces and dissipation within the dielectric layers. Wet radome caused by raining are given large impact to the received signal during the observation are operating. The more effective test due to water on the surface radome is water droplets, water-rivulets and water-spout.

To estimate the effect of radome on the GPS measurement, tests were thoroughly conducted with the following objectives:

- The impact of radome on baseline measurement.
- Analyse the accuracy of the antenna equipped with and without radome.
- Analyse the effect of water on radome surface.

3.0 EXPERIMENTAL TEST

The test involved the use of normal antenna (AT 502), choke-ring antenna (AT 504) and a hemispheric radome from LEICA. Figure 1 show the shape of hemispheric radome, AT 502 and AT 504 antennas.

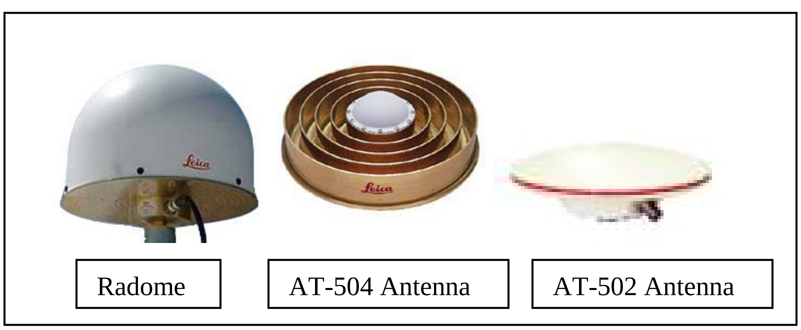

Figure 1: Radome and Antennas

Five sessions of observations have been performed. The session is divided into session A, B, C, D and E. Two GPS control stations in the UTM Campus (i.e. G08 and G06) were selected as the stations for baseline measurement. In every session, station G08 has been designated as the fixed station and station G06 as the rover station. A choke-ring antenna was permanently attached to station G08 and the type of antenna attached to station G06 was interchangeable for every session as scheduled in Table 1.

Table 1: Types of Antennas for Each Session

Sessions	Fixed station (G08)	Rover station (G06)	Simulated condition
A	AT 504	AT 502	None
B		AT 504	None
C		AT 504+radome	None
D		AT 504+radome	Water-spout
E		AT 504+radome	Water-spray

Table 1 outlines the use of antenna and condition at the rover station for each session. The first two sessions namely session A and B were performed without mounting a radome to the antenna and no simulation. The results from these two sessions will be adopted as a reference for analysis of other sessions. In session C, D and E, a choke-ring antenna equipped with a radome have been used at the rover station. The adopted simulation scenario involved the spraying of water to a radome. Session C has no simulated condition and the rest i.e., session D and E were simulated with water-spout and water-spray. These simulations act as a raining and high humidity conditions. The water pipe was spout and spray to the surface of radome during the observation, (Figure 2 and 3). As an observation method, static technique has been applied in all sessions.

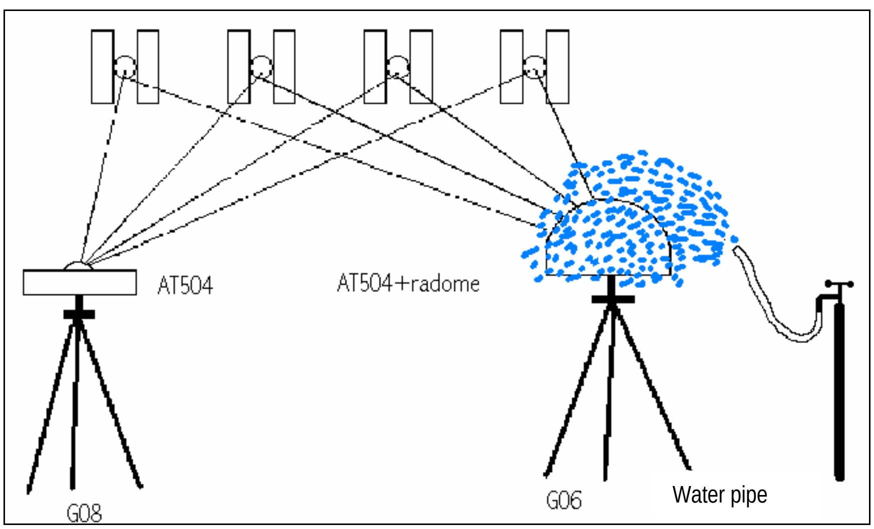

Figure 2: Waterspout during Observation for Session D

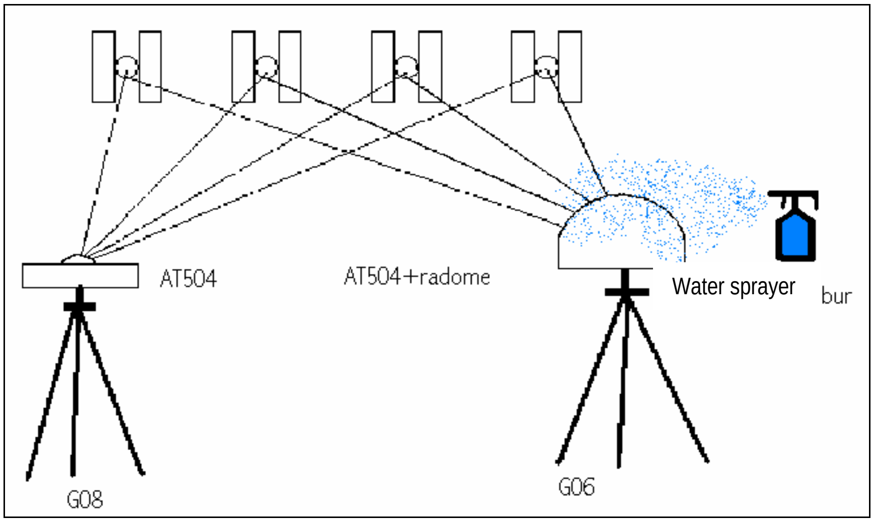

Figure 3: Water Spray during Observation for Session E

4.0 RESULT AND ANALYSIS

The carrier phase data from five sessions were processed using SKI-PRO Ver 2.1 software. As different types of antenna were applied for the observations, the antenna height and offset had to be processed carefully during the GPS data processing. In every session processing, the coordinates for station G08 was set as fixed station. For the purpose of discussion in this paper, the variation of coordinates for station G06 will be highlighted and analyzed. Table 2 shows the coordinates and associated standard errors of station G06 for sessions A, B, C, D and E.

Table 2 : Coordinates of G06 for Each Session

Sessions	A	B	C	D	E
Latitude	1º 33’ 54.32344” N	1º 33’ 54.32348” N	1º 33’ 54.32352” N	1º 33’ 54.32346” N	1º 33’ 54.32339” N
Longitude	103º 38’ 18.02007” E	103º 38’ 18.02016” E	103º 38’ 18.02015” E	103º 38’ 18.02040” E	103º 38’ 18.02021” E
Height	53.1103 m	53.1072 m	53.0928 m	53.0954 m	53.0903 m
σLat	0.0003 m	0.0003 m	0.0004 m	0.0006 m	0.0003 m
σLon	0.0005 m	0.0004 m	0.0004 m	0.0007 m	0.0004 m
σH	0.0009 m	0.0010 m	0.0010 m	0.0015 m	0.0007 m

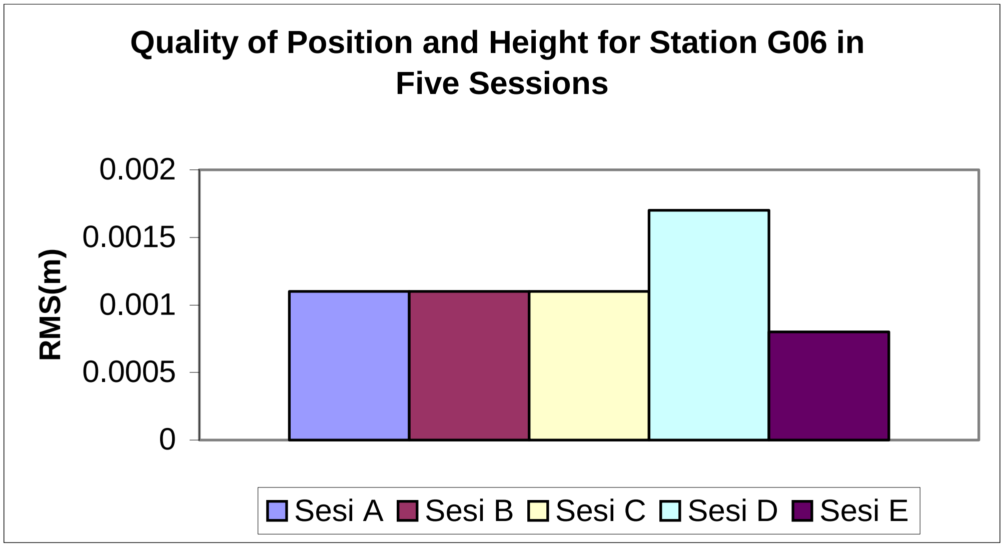

Figure 4 : Quality of Position and Height for Station G06

In addition, Figure 4 shows the quality of position and height for station G06 in five sessions. The figure indicated that, the positioning quality (Root Mean Square (RMS)) for session A, B and C are the same that is 0.0011m. Session D shows the highest value of RMS which is 0.0017m, meaning that the reliability of coordinates for this session is very poor. Nevertheless, session E gives the highest accuracy of 0.0008m.

To investigate the effect of radome on GPS measurement, the accuracy of positioning at reference (G08) and rover (G06) stations are discussed separately on the following sections.

4.1 Analysis on Reference Station

As depicted in Table 1, the reference station was fitted with AT-502 and AT-504 antennas during the tests. In order to investigate the accuracy of the measured positions, the standard deviation for each of the three dimensional coordinates (in ECEF coordinate system) has been computed. The results are astonishingly good and were presented in Figure 5. The figure indicates the standard deviation of X, Y and Z components for session A and B. The standard deviation of X, Y and Z for session A and B are 0.0006m, 0.0009m, 0.0004m and 0.0004m, 0.0010m, 0.0004m, respectively. The results suggest that session B is the most suitable to choose as a reference session for session C, D and E. Furthermore, similar type of antenna is used in all sessions.

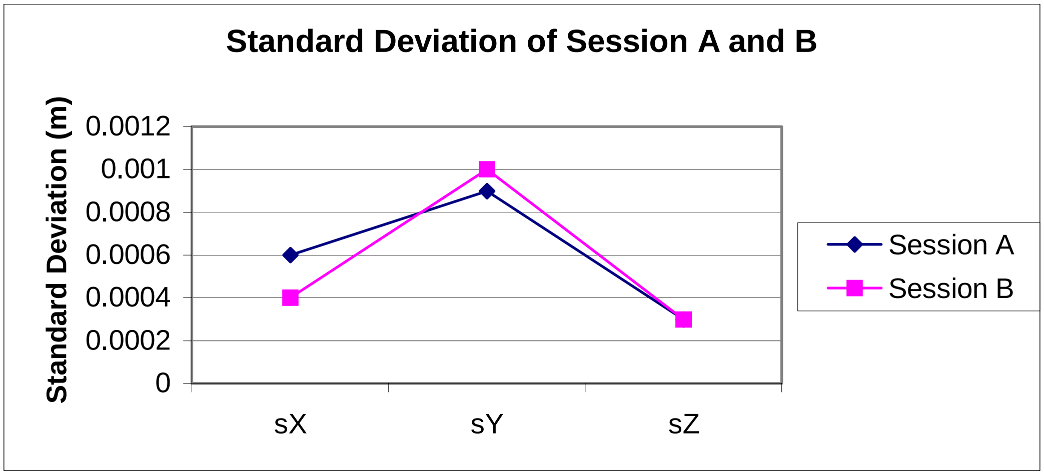

Figure 5: Standard Deviation of Session A and B

4.2 Analysis on Rover Station

Analyses on rover station were performed in order to achieve the following purposes:

- To study the impact of radome on baseline measurement.
- Accuracy analysis (positions and height) using radome.
- To study the effect of water on radome.

For comparative studies, benchmarking is based on session B.

4.2.1 The Impact of Radome on Baseline Measurement

To assess the impact of radome on GPS baseline measurement, the baseline vectors for each session have been computed. The results of baseline vectors for each session are summarized and graphically illustrated in Table 3 and Figure 6, respectively. As mentioned earlier, session B was used as a reference for baseline vector computation. It can be seen from the table and figure that session A has much better precision compared to other sessions.

Table 3: Coordinate Differences and Baseline Vector of Station G06 between Sessions A, C, D and E Session B

Session	$\Delta\phi$ (m)	$\Delta\lambda$ (m)	Δh (m)	Baseline Displacement Magnitude (m)
A	-0.0012	-0.0028	0.0031	0.0042
B	Reference	Reference	Reference	Reference
C	0.0012	0.0003	-0.0144	0.0145
D	-0.0006	0.0074	-0.0118	0.0139
E	-0.0028	0.0015	-0.0169	0.0173

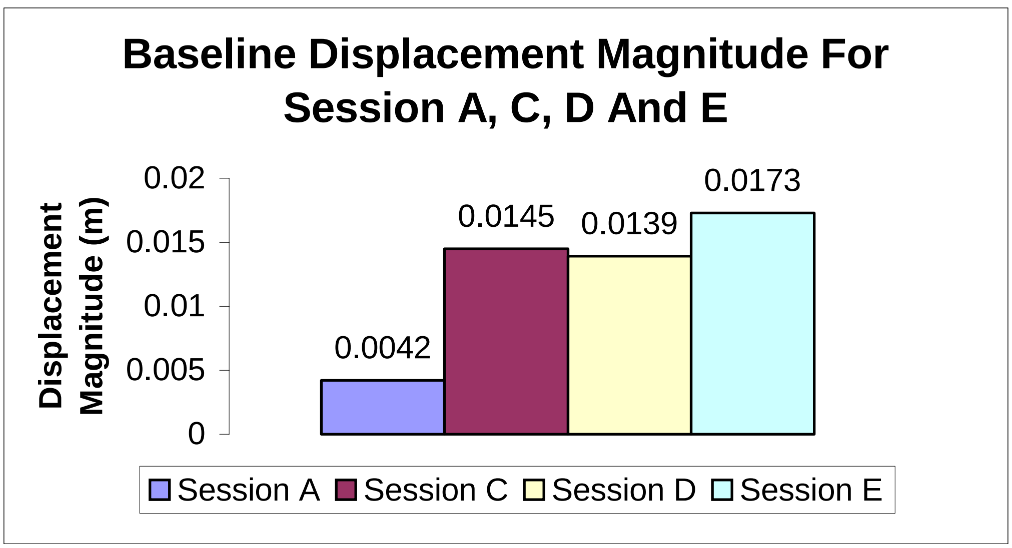

Figure 6: Comparison of Baseline Vector for Session A, C, D and E

In general the results indicate that, all the sessions which used the antenna that equipped with radome have equally came out with large value of baseline vector or displacement magnitude, i.e. more than 10mm. Conversely, session A gave a small value of baseline displacement magnitude which is less than 5mm. Considering the baseline vectors presented in the above table and figure, it would appear that the use of radome does give an impact to the magnitude of baseline.

4.2.2 Analysis on the Accuracy of Position and Height

In addition to the analysis of baseline vectors discussed in the previous section, this section deals with the analysis of the standard deviation and the quality of position and height from session A, B and C. These three sessions have been examined because they have been performed under normal condition and using different types of antenna and radome combination. Table 4 presents the results.

Table 4: Standard Deviation and Quality Position + Height for Session A, B, and C

Sessions	σLat(m)	σLon(m)	σh(m)	Quality of position and height (m)
A	0.0003	0.0005	0.0009	0.0011
B	0.0004	0.0004	0.0010	0.0011
C	0.0004	0.0004	0.0010	0.0011

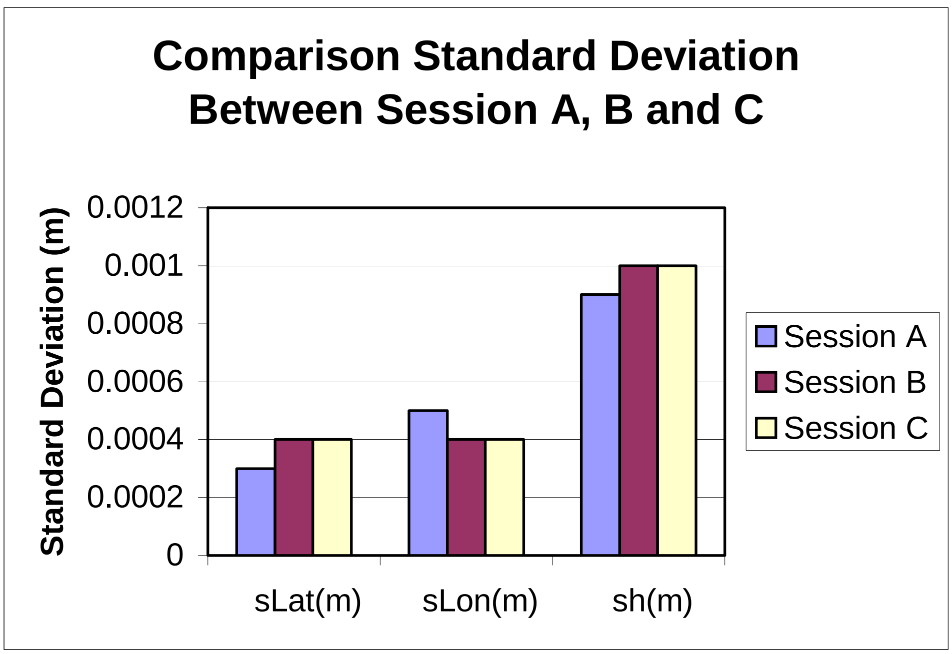

Figure 7: Comparison of Standard Deviation between Sessions A, B and C

Figure 7 illustrates more clearly the standard deviation between each session by showing the magnitude of latitude, longitude and height. In this case, the comparison of each component indicates similarity in the variation patterns between the solutions obtained using three different antenna types and combination. The difference in standard deviation for latitude, longitude and height between the three sessions is very small, nearly 0.0001m. It is immediately clear from both the table and figure that there were no significant difference in position and height of using radome in GPS measurement. Hence the results enable to reveal that radome does not give an effect on the GPS measurement process.

4.2.3 Analysis The effect Of Water on *Radome* Surface

To evaluate the effect of water on radome surfaces, it is necessary to perform simulation studies as mentioned in Section 3.0 and illustrated by Figure 2 and 3. The assessment on the effect of water in this study were examined by comparing the results of session D and E. In addition, session C has been chosen as the standard value because it has been conducted in normal condition but with the same antenna set-up. The practical significance on the effect of water was determined by examining the Geometric Dilution of Precision (GDOP) and carrier phase residuals for each session. GDOP is a factor that describes the effect of geometry on the relationship between measurement error and position error. It is used to provide an indication of the quality of the solution. Figure 10 to 12 shows the plot of GDOP for all sessions.

From Figure 8, it can be seen that the minimum and maximum value of GDOP for session C are 2.1 and 3.3., which is small. In Figure 9, minimum and maximum value of the GDOP for session D are 2.1 and 4.6, except the last five minutes toward the end of observation that gave the high value of GDOP which is 4.5 to 4.6. On average, the GDOP values are low which lie between 2.1 to 2.4. Similarly in Figure 10, the GDOP values for session E ranging from 2.1 to 2.7. In general, the GDOP values for three sessions are small and equally the same. These indicate the good satellites geometry during the observation. The main purpose of showing the GDOP plot is to prove that the satellite geometry is not a priority factor that causes the difference of satellite residuals obtained from these three sessions. Figure 11 to 13 show the satellites residuals of SV 11, SV 13 and SV 20 for these three sessions.

Figure 11 to 13 show the satellites residuals of SV 11, SV 13 and SV 20 for session C, D and E. These three satellites were plotted because they have been observed in these three sessions. Thus, they are sensible to be assessed. Figure 11 shows that the residual of SV 11 for session C and E which are in the normal level that is between 0.02m to -0.02m and highly correlated. However, the residual for session D is large and exceeding the normal level. This can be concluded that there is a disturbance to the received signal for session D. Furthermore, Figure 12 and 13 also depicted the same pattern for SV13 and SV20, respectively in session C, D and E.

The results of residual plots shown in Figure 11 to 13 indicate that in general the radome does not significantly affect GPS measurement except big drops of water such as raining or water-spout that hit on the surface. Water droplet can give impact and causes disturbance to the received GPS signal as experienced during an observation in session D.

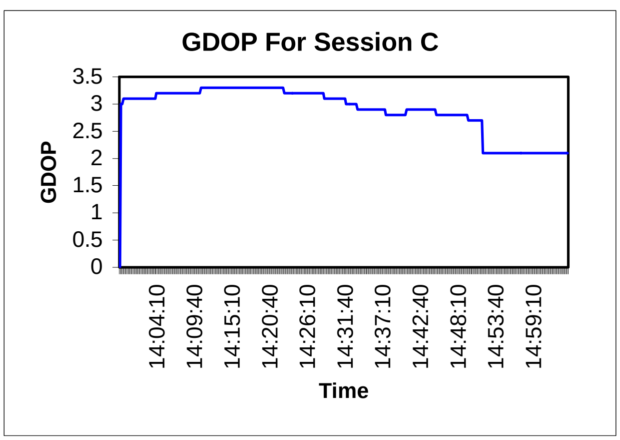

Figure 8: GDOP for session C

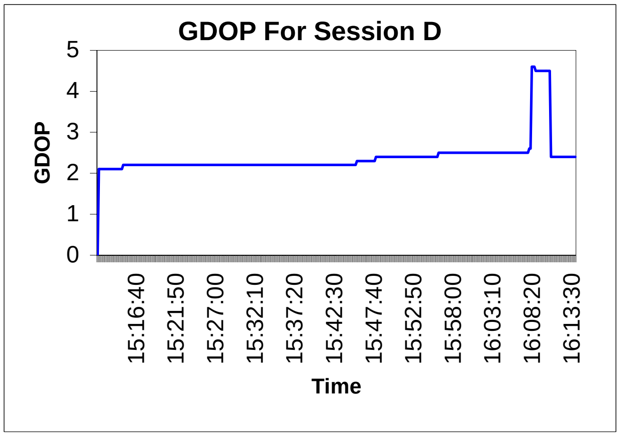

Figure 9: GDOP for Session D

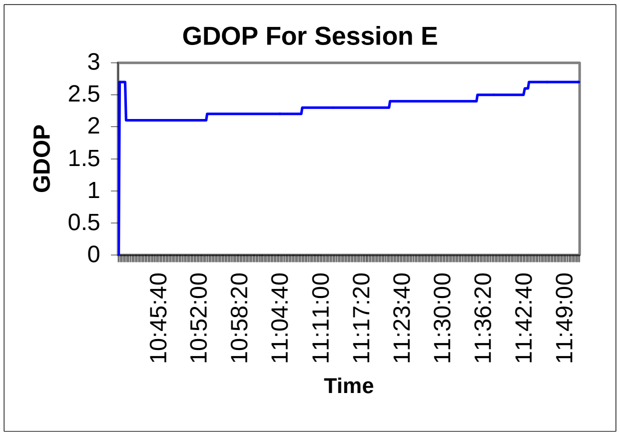

Figure 10: GDOP for Session E

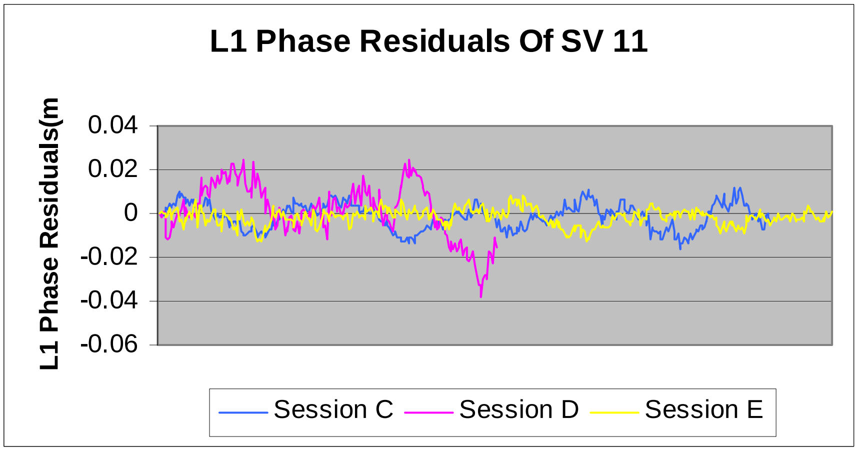

Figure 11: L1 Phase Residuals of SV11

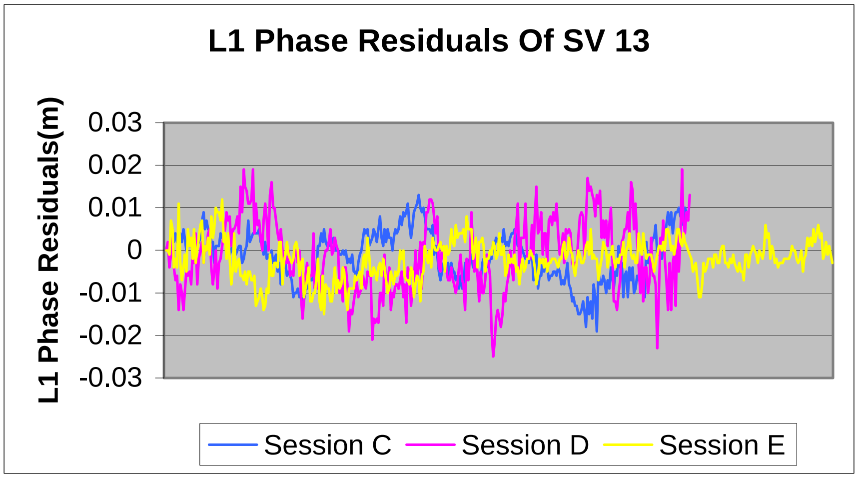

Figure 12: L1 Phase Residuals of SV13

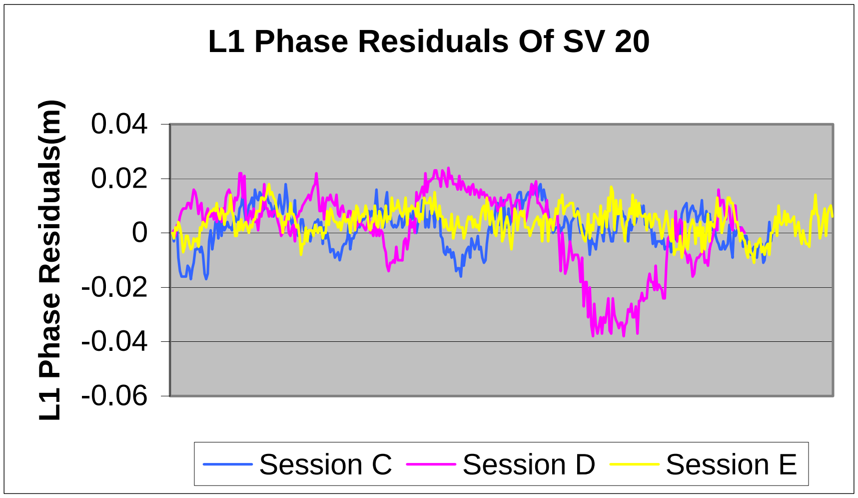

Figure 13: L1 Phase Residuals of SV20

5.0 CONCLUSION

Based on the results obtained from five GPS sessions that have been conducted, it can be concluded that:

- Radome will affect the baseline vector in GPS measurement.
- The same precision in position and height can still be achieved by using radome.
- The drops of water that hit on the surface of radome like raining will give disturbance and caused error in the received signal.

ACKNOWLEDGEMENT

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